

THE SPECTRA OF STARS

BELONGING TO

CLASS R

OF THE

DRAPER CLASSIFICATION

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE
UNIVERSITY OF MICHIGAN

By

W. CARL RUFUS

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AN INVESTIGATION OF THE SPECTRA OF STARS BELONGING TO CLASS R OF THE DRAPER CLASSIFICATION¹

By W. CARL RUFUS

INTRODUCTION

The genesis of Class R of the Draper Classification of stellar spectra may be traced from a list of "Stars Having Peculiar Spectra," published in *Harvard College Observatory Circular*, No. 9, July 9, 1896. Following the table is the statement: "Of the seven stars whose spectra are here announced as of Type IV the first, second, and seventh² (fourth), are normal. The spectra of others contain rays of much shorter wave-length than ordinary fourth type stars." This is a characteristic feature of the spectra of stars later designated as Class R and is here attributed to four stars, DM. — 38° 12843, + 85° 332, — 12° 5755, and + 5° 5223. Two other stars of the list, DM. — 31° 15954 and — 29° 15574, whose spectra were described as peculiar, but not associated with the four previously mentioned, have also been assigned to this class. These six stars constitute the nucleus of Class R.

Later announcements of stars having peculiar spectra increased the number possessing the com-

mon characteristics, "rays of shorter wave-lengths than the ordinary fourth type stars," and "a strong band extending from about $\lambda 461 \mu\mu$ to $\lambda 471 \mu\mu$." These stars were frequently referred to as belonging to "the same class as Z.C. 10^b 2112 described above", or "the same type as C.D.M. — 47° 6614, described in *Circular*, No. 76." A more convenient method of reference seemed to warrant the addition of a new class, which was suggested by Professor Pickering in *Harvard Circular*, No. 145, "A Sixth Type of Stellar Spectra," published December 1, 1908. A table of "Stars Having Spectra of Class R," containing sixty-one stars is given in *Harvard Annals*, Volume 56, page 220. A few others are known. In order to complete the list to date Table I is appended. The successive columns give the star's designation, right ascension and declination for 1900, Durchmusterung magnitude, Harvard photometric magnitude, galactic longitude and latitude, date of discovery, name of discoverer, and reference concerning announcement.

PURPOSE OF THIS INVESTIGATION

I. We propose to study the relationship between the spectra of stars of Class R and stars of Class N.

That a close relationship exists is evident from the fact that many Class R stars were announced

¹A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

²In a letter dated February 11, 1915, Professor E. C. Pickering says: "In *Harvard Circular* 9, the word 'fourth' should be substituted for 'seventh' in the passage you quote."

TABLE I. STARS WITH SPECTRA OF CLASS R NOT INCLUDED IN TABLE XI, PAGE 220, VOLUME 56, ANNALS OF THE HARVARD COLLEGE OBSERVATORY.

STAR.	R. A. 1900.	DECL. 1900.	MAGNITUDE.		GALACTIC		DATE.	DISCOVERER	REFERENCE.
			D. M.	H. P.	LONG.	LAT.			
+ 23° 123	0 ^h 48 ^m .9	+ 23° 32'	8.3	8.8	91°	— 32°	1914	Cannon	H. C. 184
+ 14 1598	7 7 .2	+ 14 46	Var.	9.2	171	+ 12	1914	Cannon	H. C. 184
— 14 4371	16 7 .6	— 14 57	9.5	...	326	+ 24	1910	Fleming	H. C. 158
+ 42 2811	17 10 .4	+ 42 15	7.3	7.74	37	+ 34	1914	Cannon	H. C. 184
Uncertain	17 33 .5	— 57 52	...	...	302	— 15	1901	Fleming	H. C. 60
									H. A.
									56, 223
— 3 5751	23 57 .0	— 3 23	9.2	9.9	63	— 64	1914	Cannon	H. C. 184

as having a spectrum of Type IV (N), or resembling Type IV with peculiarities (N_p). Parkhurst expresses this condition by stating, "No sharp line can be drawn between Classes N and R."³

2. We propose also to study the relationship between stars of Classes R and N on the one hand and stars of the Harvard sequence (B, A, F, G, K, M) on the other.

Concerning stars of the fourth type Miss Clerke says:⁴ "They have indeed traceable relationships; but the genealogy obscurely indicated by them needs authentication." Vogel in 1874 proposed that Secchi's Types III (Harvard K, M) and IV (Harvard R?, N) be considered in one class and designated as IIIa and IIIb. Hale, Ellerman, and Parkhurst in a valuable treatise on "The Spectra of Stars of Secchi's Fourth Type"⁵ reached the conclusion: "Stars of the third and fourth types should therefore be classed together, as coordinate branches leading back to stars like the sun."

Pickering, in the letter previously referred to, says: "We have not been able to establish the sequence between classes M and R. Owing to the intensity of the blue light and the presence of lines H and K in stars of Class R, it seems more probable that Class R should fall between M and N."

In particular the thesis is proposed: Stars belonging to Class R of the Draper Classification of stellar spectra form the connecting links between stars of the solar type (G) and stars of Class N; and stars of the two classes, R and N, form a branch of the sequence arranged in order of stellar evolution coordinate with the branch consisting of stars of Classes K and M.

Furthermore, it is hoped that the quantitative and qualitative data obtained during this investigation will contribute in some measure to the broader problem of stellar evolution in general.

GENERAL CHARACTERISTICS

The table of Class R stars contains 66 members, none of which is brighter than the seventh

³ The Spectra and Colors of Red Stars of Harvard Classes N and R. *Astrophysical Journal*, Vol. 35, p. 125.

⁴ *Problems in Astrophysics*, p. 215.

⁵ *Publications of the Yerkes Observatory*, Vol. 2 p. 385, 1903.

visual magnitude. Among the number whose magnitude is given there are:

VISUAL MAGNITUDE.	TOTAL NUMBER.	NORTH OF -20° .
7.0 to 7.9	7	5
8.0 to 8.9	13	8
9.0 to 9.9	30	13
10.0 to 10.9	6	0

Five are marked as having a variable magnitude. Only twenty are in the northern hemisphere. Not as great preference seems to be given for the galactic region as in the case of Classes N, B, and O.

The following table, showing the distribution of stars of various spectral classes with reference to the Galaxy, is based upon the work at Harvard⁶ as summarized by Russell⁷ with the data for Class R stars added by the writer. The count for Class R was made for the region $+30^\circ$ to -30° galactic latitude. The Harvard count for the other classes varied from these limits in different regions on account of the irregularity of the Galaxy.

Class	O	B	A	F	G	K	M	R	N
Percentage in Galactic Region	100	82	66	57	58	56	54	63	87

The color of Class R stars has been referred to as "probably yellow like the stars of the second type."⁸ This characteristic is suggested as one of the features distinguishing stars of Class R from those of Class N:⁹ "Stars having spectra of the fourth type are commonly regarded as red stars;" which indicates that the Harvard observers considered that, in general, stars of Class R are not red. Miss Clerke referred to two of the number as "white stars"¹⁰ — $10^\circ 5057$ and $-10^\circ 513$.

⁶ *Harvard Annals*, Vol. 64, p. 134.

⁷ *Publications American Astronomical Society*, Sixteenth Meeting, p. 26.

⁸ *Harvard Annals*, Vol. 56, p. 219.

⁹ *Harvard Circular*, 145, p. 3.

¹⁰ *Problems in Astrophysics*, p. 221.

Parkhurst has determined the color index of five stars of the list as follows:

STAR.	COLOR INDEX.
— 10° 5057	1.09
+ 85 332	1.56
+ 53 66	1.66
+ 20 5071	1.82
+ 6 3898	2.37

Compared with his results for the color index of nine stars classed as N and Na (1.94 to 3.26) it appears that in general stars of Class R are not as red as those of Class N. He reaches the conclusion, however, that the expression "Fourth-Type Stars not Red," seems inappropriate;¹¹ and he apparently includes Class R stars in the expression, Fourth-Type Stars.

The difference in color between stars of these classes (N and R) as seen by visual observers may be tested by referring to any catalogue of red stars. Birmingham-Espin's catalogue of 766 red stars contains only two out of twenty stars of Class R from the seventh to the ninth magnitude, DM. + 61° 667 and — 3° 1685; while it catalogues seventy per cent. of the stars of Class N within the same range of magnitude. The difference in color between the two classes was clearly discernible during our observations, forming a gradual transition from Class R to Class N with increasing redness.

The following table is inserted to show the change in color index with spectral type. It gives the mean of the values obtained by different observers and tabulated by Russell.¹² The value for Class R has been added by the writer.

The general characteristics of the spectra of stars of Class R are given in the various circulars previously referred to and include:

1. Rays of much shorter wave-length than ordinary fourth-type stars.
2. The blue end is no longer cut off but extends to as short a wave-length as in spectra of Class K.
3. The lines H and K are well shown.

¹¹ *Astrophysical Journal*, Vol. 35, p. 132, 1912.

¹² *Publications American Astronomical Society*, Sixteenth Meeting p. 27.

4. One or more dark bands, resembling the spectrum of the fifth type reversed on a continuous spectrum.

5. Two well-marked absorption bands, one of which has a center near the calcium line λ 4227, the other extending from λ 4640 to λ 4750.

COLOR INDICES OF STARS BY SPECTRAL TYPES.

CLASS OF SPECTRUM.	AVERAGE COLOR INDEX.
B 0	— 0.32
B 5	— 0.19
A 0	0.00
A 5	0.00
F 0	0.38
F 5	0.58
G 0	0.80
G 5	1.02
K 0	1.27
K 5	1.64
M	1.65
R	1.7
N	2.5

Further indication of the relation of these spectra to others is found in the following remarks:

1. "It appears probable that stars can be found forming a continuous sequence from Class N to Class R, like that connecting Class B and Class M." *Harvard Annals*, Vol. 56, p. 220.

2. The designation N5R is applied to three stars of intermediate type listed in "Stars of Class N." *Harvard Annals*, Vol 56, p. 219, Remark 5.

The order of the sequence from Class N to Class R suggested above and applied in the notation N5R appears to be inconsistent with the order of the sequence connecting Class B and Class M with which it is compared. The well established sequence, B A F G K M, is usually assumed to represent the order of stellar evolution. Now, if Classes N and R are closely related and are considered to be late types according to Hale, Pickering and other authorities, the larger color index or increasing redness of the stars of Class N, due to the gradual weakening in intensity of rays of shorter wave-length, demands a reversal of the order suggested and the adoption of the order from Class R to Class N and the notation R5N. This is apparent in any classifica-

tion that places Class N near the end of the list. In addition to the system mentioned above, Lockyer's classification based upon his meteoritic hypothesis also makes Class N a late type. Russell,¹³ however, prefers to assign this class a position near the beginning of the process of stellar development.

OBSERVATIONS

The original program of observations included all known stars of Class R down to the ninth visual magnitude observable in the latitude of Ann Arbor, also a sufficient number of stars of Classes N and O for the purpose of comparison and contrast. The suggestion that the spectrum of stars belonging to Class R resembles the spectrum of the fifth type reversed on a continuous spectrum prompted the inclusion of a number of stars of Class O. It was soon discovered that the resemblance was one of a very general nature, better illustrated by photographs taken with an objective prism spectrograph than with a slit spectrograph; the details brought out by the latter detract from the resemblance, and apparently give no additional clue to a physical relationship between these classes of stars.

All these spectrograms were made with the one-prism spectrograph attached to the 37½-inch Reflector of the Detroit Observatory. Since this spectrograph has been fully described by Professor Curtiss,¹⁴ we will mention only the following features.

Focal length of collimator	686 mm.
Aperture of collimator	36.6 mm.
Refracting angle of prism	64°.5
Focal length of camera	420 mm.
Linear dispersion at λ 4500	47.7 angstroms per mm.

The focal plane of the camera is sensibly flat for the range of spectrum of this investigation λ 4000 to λ 5000. The minimum deviation setting is for H γ rays.

Seed plates were used exclusively, 23's and 27's for stars of Class O, 27's and Graflex for stars of Classes N and R. The coarseness of the silver grains of the Graflex plates and a tendency to form bubbles in the film during the process of development renders them much less satisfactory

than the 27's excepting for the faintest stars, where accuracy of measurement was sacrificed for speed during exposure.

A determination of the slit width for the setting 36.0 based upon the measurement of thirty comparison lines on plates 3063A, 3039B, and 3055A, and the ratio of the focal length of the collimator to the focal length of the camera gave the approximate value 0.075 mm.¹⁵ A titanium spark has been used for comparison on all the plates.

The accompanying table of observations, Table II, only partially reveals the arduousness of the observational work. The visual faintness of the stars of Class R and the relatively small amount of blue light combined to render the photography of their spectra difficult under the most favorable conditions, and the success of the work is a testimony to the efficiency of the apparatus used. Frequently an exposure begun under apparently favorable conditions and continued for two or three hours was interrupted before completion by clouds or haze and the exposure time was entirely lost or the spectrogram was so faint that its weight was small for radial velocity and wavelength determination. The work begun at Mount Wilson on stars of Classes N and R with the 60-inch Reflector has been temporarily discontinued, because it was found that the exposures require so much time. Mr. Van Maanen writes, January 23, 1915: "We are waiting for the time when there will be more time available or when we will be able to use a more powerful instrument."

In Table II, C.S.T. refers to Central Standard Time. The seeing (S) and transparency (T) are estimated on a scale 5. The temperature at the beginning (B) and end of exposures (E) are recorded in degrees Centigrade. Slit width (W) for setting 36.0 is approximately 0.075 mm.; the pitch of the screw is one-half millimeter and the head has 100 divisions. The length (L) of the slit is approximately 0.34 mm. for setting 0.8 and 0.46 mm. for setting 1.5, giving a spectrum approximately 0.20 to 0.27 mm. in width respectively.

¹³ *Publications American Astronomical Society*, Sixteenth Meeting.

¹⁴ *Publications of the Astronomical Observatory of the University of Michigan*, Vol. 1, p. 37.

¹⁵ Plaskett has found that the exposure time in average seeing is almost inversely proportional to slit-width until this reaches at least 0.075 mm. *Astrophysical Jour.*, Vol. 28, p. 259, 1908. With this slit-width the fainter lines begin to disappear.

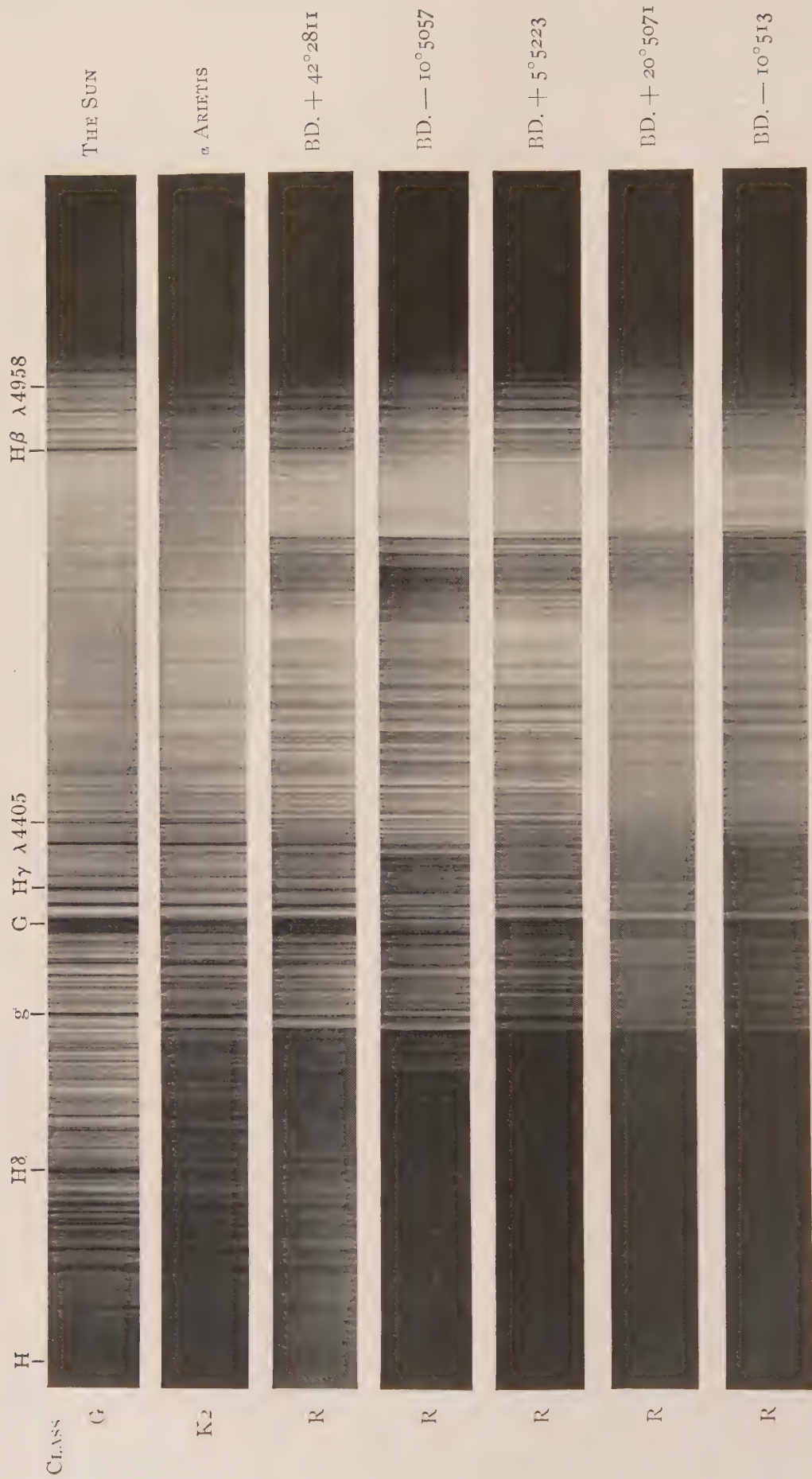


PLATE G. CLASS G, CLASS K2 AND EARLIER CLASS R STELLAR SPECTRA COMPARED

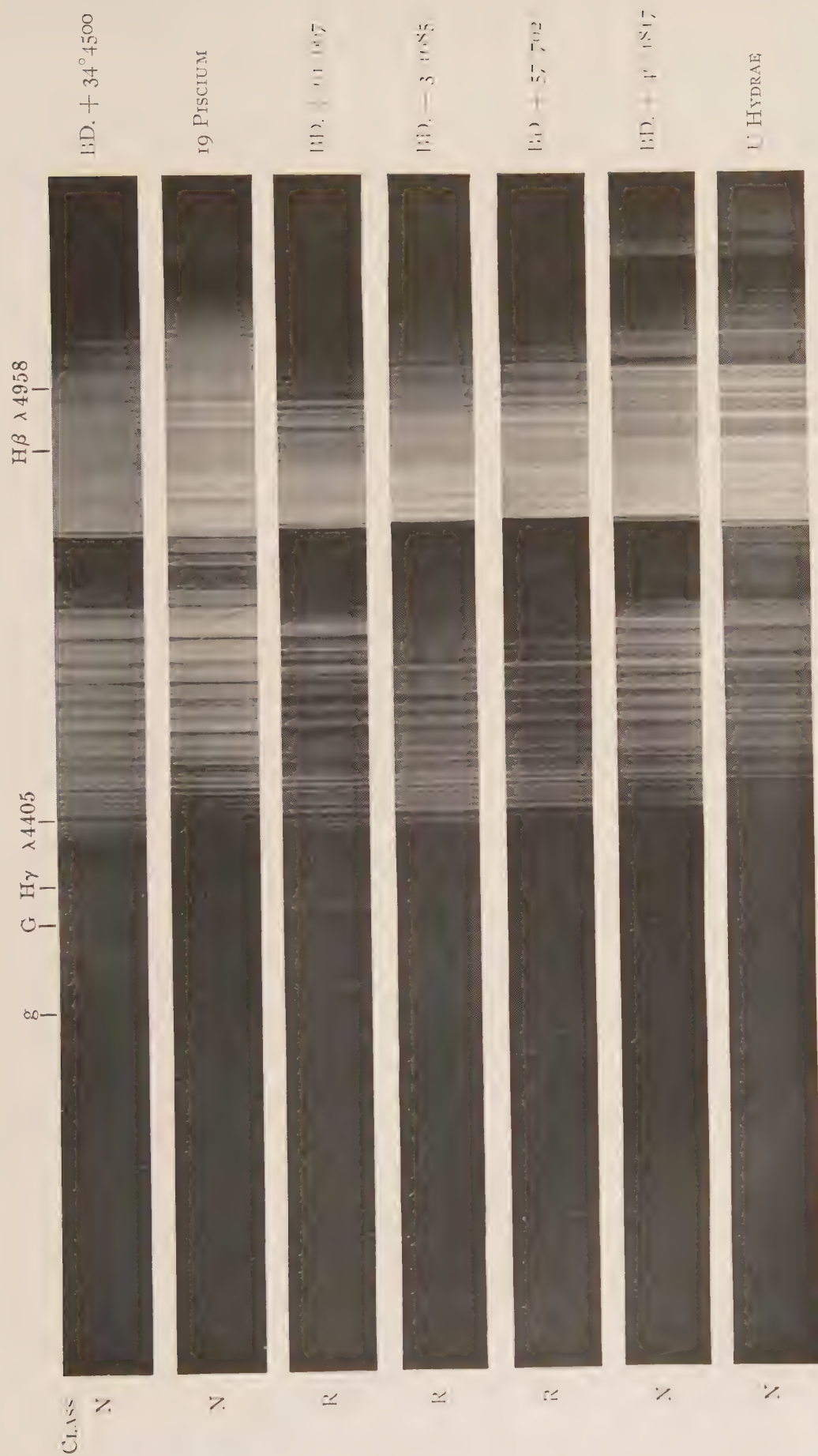


PLATE H. CLASS N AND LATE CLASS R STELLAR SPECTRA IN THE PHOTOGRAPHIC REGION

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TABLE II. JOURNAL OF OBSERVATIONS. CLASS R.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME TEM- PERATURE.		INSIDE TEM- PERATURE.		SLIT.		REMARKS.	
						B.	E.	B.	E.	W.	L.		
DM. — 10° 5057. R.A. 19 ^h 17 ^m .6; Decl. — 10° 54'. Mag. : DM. 7.0, H.P. 7.04.													
2882 A	1914 July	1	9:50 to 12:40	27	2	2.5	17.4	16.0	18.60	18.52	35.0	1.5	Stopped by clouds.
2887 A	July	3	10:00 to 13:20	27	2.5	3	18.3	18.0	20.93	20.70	35.0	1.5	
2914 A	July	15	10:14 to 13:44	27	2	2.5	23.0	22.0	24.80	24.60	35.0	1.5	Fog near end of exposure.
2915 A	July	17	9:17 to 12:47	27	1.5	4	21.3	20.0	25.55	25.32	35.5	1.3	
2923 A	July	21	11:32 to 15:02	27	2	3	25.0	21.8	25.75	25.38	36.5	1.0	
2958 A	Aug.	12	10:30 to 13:00	27	2	3	20.1	18.2	20.95	20.84	37.0	1.0	Hazy toward end.
DM. + 20° 5071. R.A. 21 ^h 59 ^m .7; Decl. + 20° 34'. Mag. : DM. 8.7.													
2942 A	1914 Aug.	3	8:50 to 14:20	27	1	3	17.8	14.8	25.25	24.98	36.5	1.0	Trace only.
2966 C	Sept.	4	8:20 to 16:00	27	2	3	16.1	11.6	17.78	17.45	36.0	0.8	
2967 A	Sept.	6	8:15 to 16:15	27	2	3	19.4	13.8	19.80	19.56	36.0	0.8	
2968 A	Sept.	8	7:05 to 16:15	27	2	2.5	12.8	8.0	14.91	14.57	36.0	0.8	Fleecy clouds, 14:00 to 15:00.
DM. + 5° 5223. R.A. 23 ^h 44 ^m ; Decl. + 5° 50'. Mag. : DM. 8.7.													
2988 A	1914 Sept.	17	8:45 to 16:15	27	2	2	18.9	15.7	19.69	19.62	36.0	0.8	Clouds, 10:45 to 11:45.
2989 B	Sept.	18	9:20 to 16:20	27	2.5	3	19.7	14.0	20.27	19.95	36.0	0.8	Hazy, 2:00 to 2:30.
DM. + 57° 702. R.A. 3 ^h 3 ^m .8; Decl. + 57° 31'. Mag., DM. 7.9, H.P. 8.06.													
3044 A	1914 Oct.	31	12:05 to 17:25	Graf.	2	2	10.5	8.2	11.12	10.97	36.0	1.0	Light clouds, 1:00 to 3:00.
3079 A	1915 Jan.	2	7:10 to 13:10	Graf.	2	3	-8.6	-12.2	-5.40	-5.54	36.0	0.8	
DM. — 10° 513. R.A. 2 ^h 30 ^m ; Decl. — 9° 53'. Mag., DM. 8.0, H.P. 8.26.													
3038 C	1914 Oct.	25	8:50 to 10:30	Graf.	1	1	7.8	....	7.82	....	36.0	1.0	Incomplete.
3039 B	Oct.	30	8:30 to 13:00	Graf.	2	3	8.1	6.0	10.43	10.33	36.0	1.0	
3055 A	Nov.	11	9:55 to 11:55	27	2	2	2.8	2.2	5.21	5.18	36.0	0.8	Hazy after 11:30.
3063 A	Nov.	23	9:00 to 13:20	27	1.5	3	-3.3	-4.6	-3.23	-3.28	36.0	0.8	Hazy after 1:00.

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TABLE II. JOURNAL OF OBSERVATIONS. CLASS R. Continued.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME TEM- PERATURE.		INSIDE TEM- PERATURE.		SLIT.		REMARKS.
						B.	E.	B.	E.	W.	L.	
DM. + 61° 667. R.A. 3 ^h 57 ^m .2; Decl. + 61° 31'. Mag., DM. 7.5, H.P. 7.92.												
3051 A	1914 Nov. 6	11:15 to 13:00	Graf.	2	2	3.8	4.2	6.44	6.40	36.0	0.8	Cloudy at 12:30.
3054 C	Nov. 10	12:15 to 14:45	Graf.	1.5	2	4.8	3.1	5.02	5.00	36.0	0.8	Stopped by clouds.
3064 C	Nov. 23	13:45 to 15:00	Graf.	1.5	2	-4.6	-4.2	-3.30	-3.29	36.0	1.0	Stopped by haze.
3073 A	Dec. 21	10.05 to 15.05	Graf.	1.5	3	-12.4	-14.4	-7.66	-7.78	36.0	0.8	Interrupted by clouds.
3088 A	1915 Jan. 23	7:53 to 14:03	27	1	3	-10.6	-16.0	-7.54	-7.61	36.0	1.0	Incomplete.
3089 A	Jan. 26	6:50 to 13:20	Graf.	2	3	-7.0	-9.5	-7.44	-7.55	36.0	1.0	
DM. - 3° 1685. R.A. 6 ^h 56 ^m ; Decl. - 3° 7'. Mag., DM. 7.7, H.P. 7.06.												
3087 A	1915 Jan. 20	10:05 to 12:30	Graf.	1	3	-7.2	-10.0	-3.07	-2.60	36.0	1.0	Stopped by clouds.
3094 D	Feb. 8	7:05 to 12:35	27	1.5	4	-6.4	-9.5	-3.42	-3.64	36.0	1.0	
3097 A	Feb. 17	7:00 to 11:30	Graf.	2.4	4	-1.8	-3.8	-0.06	-0.08	36.0	1.0	
DM. + 34° 1929. R.A. 8 ^h 53 ^m .6; Decl. + 34° 9'. Mag., DM. 8.9.												
3138 B	1915 Mar. 11	7:40 to 14:00	Graf.	2	4	0.0	....	1.25	1.10	36.0	0.7	
3143 A	Mar. 16	7:15 to 13:15	Graf.	1.5	4	-1.2	-4.5	2.05	1.87	36.0	0.8	
DM. + 14° 2048. R.A. 9 ^h 8 ^m .3; Decl. + 14° 37'. Mag. DM. 8.8, H.P. 8.68.												
3126 A	1915 Mar. 2	7:35 to 10:35	Graf.	1.5	2.5	-3.0	-7.1	-1.04	-1.12	36.0	0.8	Stopped by clouds.
3127 A	Mar. 3	7:55 to 12:55	Graf.	2	2	-4.6	-6.4	-4.78	-4.72	36.0	0.8	Hazy after 12:00.
3134 A	Mar. 8	7:30 to 12:30	Graf.	2	3	-2.4	-4.4	-2.60	-2.48	36.0	0.8	
DM. + 42° 2811. R.A. 17 ^h 10 ^m .4; Decl. + 42° 15'. Mag., DM. 7.3, H.P. 7.74.												
3128 B	1915 Mar. 3	13:05 to 14:15	Graf.	2	2	-7.0	-7.5	-4.75	-4.75	36.0	0.8	Stopped by clouds.
3135 B	Mar. 8	12:45 to 15:45	27	1.5	3	-4.6	-5.7	-2.52	-2.55	36.0	0.8	
3144 B	Mar. 16	13:30 to 17:10	27	2	4	-4.8	-5.7	1.85	1.81	36.0	0.8	
3169 A	Apr. 3	11:50 to 16:50	27	2	3	-1.4	-3.0	1.46	1.40	36.0	0.8	Continued until near dawn.

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TABLE II. JOURNAL OF OBSERVATIONS. CLASS N.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOVE TEM- PERATURE.		INSIDE TEM- PERATURE.		SLIT.		REMARKS.
						B.	E.	B.	E.	W.	L.	

DM. — $5^{\circ} 48' 58''$. V Aquilæ. R.A. $18^h 59^m .1$; Decl. — $5^{\circ} 50'$. Mag. DM. 7.0, H.P. Var.

2902 D	1914 July 6	10:33 to 14:33	27	2	3	2.07	1.76	24.22	23.92	35.0	1.5	Trace only.
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DM. + $76^{\circ} 7' 34''$. R.A. $19^h 25^m .1$; Decl. + $76^{\circ} 22' .1$. Mag., DM. 6.5, H.P. Var.

2883 B	1914 July 1	12:59 to 14:49	27	2.5	3	15.8	15.8	18.52	18.50	35.0	1.5	
2821 C	July 20	9:40 to 12:10	27	2	3.5	23.0	22.0	24.11	23.95	35.5	1.5	

19 Piscium. R.A. $23^h 41^m .3$; Decl. + $2^{\circ} 56'$. Mag., DM. 6.2, H.P. Var.

2965 B	1914 Sept. 2	10:25 to 13:30	27	1	3	15.4	15.5	22.45	22.39	35.0	1.5	Clouds 25 min.
2977 B	Sept. 11	8:55 to 11:25	27	1.5	3	11.2	10.3	13.21	13.20	35.0	1.5	
2978 D	Sept. 11	11:48 to 14:18	27	2	3	10.1	8.5	10.19	13.01	34.0	1.0	

DM. + $34^{\circ} 45' 00''$. R.A. $21^h 37^m .8$; Decl. + $35^{\circ} 3' .1$. Mag., DM. 6.2, H.P. Var.

2916 D	1914 July 17	13:02 to 15:22	27	2	4	20.0	18.5	25.32	25.30	35.5	1.3	
2922 B	July 20	12:28 to 14:48	27	2.5	3	22.0	18.8	23.99	23.85	35.5	1.5	

U Hydræ. R.A. $10^h 32^m .6$; Decl. — $12^{\circ} 52'$. Mag., DM. Var., H.P. Var.

3084 A	1915 Jan. 14	12:37 to 15:07	Graf.	1.5	3	-1.5	-2.5	-0.61	-0.63	36.0	1.0	
3086 B	Jan. 15	13:05 to 15:15	Graf.	2	1	-3.5	-3.6	-1.60	-1.61	36.0	1.0	
3090 D	Jan. 26	13:45 to 16:30	Graf.	1.5	3	-9.5	-9.7	-7.60	-7.62	36.0	1.0	
3098 B	Feb. 17	11:45 to 14:00	27	2	4	-3.9	-4.3	-0.09	-0.10	36.0	1.0	
3168 C	Apr. 3	8:15 to 10:45	27	2	4	+0.5	-1.0	1.49	1.47	36.0	0.8	

DM. + $46^{\circ} 18' 17''$. R.A. $12^h 40^m .4$; Decl. + $45^{\circ} 58'$. Mag., DM. Var., H.P. Var.

3085 B	1915 Jan. 14	15:22 to 17:22	Graf.	2	3	-2.4	-3.6	-0.65	-0.65	36.0	1.0	
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SPECTRA OF CLASS R STARS

TABLE II. JOURNAL OF OBSERVATIONS. CLASS O.

PLATE.	DATE.	EXPOSURE. C. S. T.	PLATE	S.	T.	DOME TEM- PERATURE.		INSIDE TEM- PERATURE.		SLIT.		REMARKS.
						B.	E.	B.	E.	W.	L.	

DM. $+35^{\circ} 3053$. R.A. $20^{\text{h}} 2^{\text{m}}.2$; Decl. $+35^{\circ} 31'$. Mag., DM. 7.0, H.P. 7.01.

2938 A	1914 July 29	12:00 to 2:15	27	1.5	4	15.5	14.6	19.05	18.76	35.5	1.0	
2950 A	Aug. 5	11:40 to 12:40	27	2	3	20.6	19.0	22.96	22.85	35.5	1.0	

DM. $+43^{\circ} 3571$. R.A. $20^{\text{h}} 17^{\text{m}}.1$; Decl. $+43^{\circ} 32'$. Mag., DM. 7.5, H.P. 6.83.

2982 D	1914 Sept. 14	12:43 to 14:38	27	1	3	16.8	16.2	17.57	17.53			Cloudy near end.
3012 B	Oct. 1	11:08 to 12:58	27	3	3.5	11.0	10.0	13.37	13.32	34.0	1.8	

DM. $+37^{\circ} 3821$. R.A. $20^{\text{h}} 8^{\text{m}}.5$; Decl. $+38^{\circ} 3'$. Mag., DM. 7.1, H.P. 7.44.

2981 A	1914 Sept. 13	11:35 to 13:35	27	2	2	14.1	13.8	15.10	15.09	34.0	1.0	Interrupted by clouds. Spoiled in developing.
2990 A	Sept. 19	12:15 to 14:00	27	2.5	3	19.2	19.2	21.06	21.07	34.0	1.5	
3011 A	Oct. 1	9:03 to 10:53	27	3	4	12.8	11.1	13.40	13.37	34.0	1.8	

λ Cephei. R.A. $22^{\text{h}} 8^{\text{m}}.1$; Decl. $+58^{\circ} 56'$. Mag., DM. 5.6, H.P. 5.19.

2933 A	1914 July 27	12:27 to 12:57	27	2	3	19.6	19.1	25.67	25.58	34.5	2.0	
2934 B	July 27	13:03 to 14:23	23	2	3	19.1	19.0	25.58	25.55	34.5	2.0	
2952 C	Aug. 5	14:08 to 14:23	23	2	3	18.9	18.9	21.84	21.84	34.5	2.0	
2953 B	Aug. 5	14:55 to 15:20	23	2	2	18.9	18.9	21.83	21.83	34.5	2.0	
2979 A	Sept. 11	14:40 to 15:40	23	2	3	8.5	8.0	12.90	12.92	34.0	1.0	
2983 B	Sept. 14	14:57 to 15:27	23	1.5	2.5	16.2	16.1	17.53	17.50	34.0	1.5	
2984 C	Sept. 14	15:37 to 16:07	23	1.5	2.5	16.0	15.8	17.50	17.48	33.0	2.0	

THE SPECTROGRAMS

The spectra of stars of Class R are marked by strong absorption bands, numerous dark lines, and a few bright lines. Only plates of the stars $+42^{\circ} 2811$ and $-10^{\circ} 5057$ gave a spectrum above $\lambda 4188$ strong enough for the measurement of lines; sufficient continuous spectrum is visible, however, beyond this limit on plates of other stars to indicate the presence of violet rays. The H and K lines are clearly seen on plates of $+42^{\circ} 2811$. Some plates show a sharp drop in intensity at λ

4216, others fade away gradually. The calcium line $\lambda 4227$ is strong. The broad G group, extending in some cases from $\lambda 4295$ to $\lambda 4315$, is the most prominent feature of this region, showing almost complete absorption on some of the plates. The line $\lambda 4384$ is conspicuous. $\text{H}\gamma$ is present, but is not prominent. On plates of the stars showing the strongest ordinary bands, there is also strong absorption from $\lambda 4395$ toward the violet rendering the spectrum very weak as far as $\text{H}\gamma$ or even as far as G in some cases. The

most prominent feature of the whole spectrum under consideration, from the violet end to λ 5000, are the strong absorption bands with head at λ 4737 when the bands are weaker and at λ 4752 when they are stronger. These bands are sharply defined toward the red but gradually fade away toward the violet, usually to about λ 4630-40. The continuous spectrum on the red side of these bands is much stronger than it is on the other side, the relative intensity differing greatly in the different stars; in general, the spectrum showing the stronger absorption bands suffers the greater loss in intensity on the violet side. An absorption line varying in intensity in the different stars occupies the position of $H\beta$, but a companion line and the low dispersion in this region renders its identification difficult. On some plates it is very weak, on others not discernible. $H\beta$ does not clearly appear as a bright line on any plate. The intensity of the spectrum, which is a maximum in the broad bright zone adjoining the head of the strong absorption band, gradually grows less toward the red limit of visibility of the photographic plate; at λ 5000 the spectrum is much fainter for Class R stars as a rule than for Class N stars taken under the same conditions. Prominent lines varying in intensity from star to star are found at $\lambda\lambda$ 4876, 4886, 4921, 4958, and 4985.

The features here mentioned will be discussed in the section on qualitative results.

MEASUREMENT AND REDUCTION

Measurement. The spectrograms were measured on Measuring Engines No. 1 and No. 3 of this Observatory. The pitch of the screws is one-half millimeter and the least reading 0.0005 mm. Determinations of the periodic error for different sections indicate that no corrections to the micrometer readings are necessary. Low magnifying power gave the best results on account of the coarseness of the silver grains of the photograph plates used; for the Graflex plates power 7 to 8 was used, for 27's power 12 to 15. All the available star lines were measured for wavelength determination. About 25 comparison lines were measured on each plate. The average of three settings on a star line was taken. The mean of two readings on the inner tip of the upper comparison line was averaged with the mean of

two readings on the inner tip of the lower. This has a double advantage: in the first place, if the point is fairly symmetrical its bisection gives a better result than the bisection of a broad line; and in the second place, the effect due to the curvature of the slit image on the plate is minimized. In our work the curvature correction was not appreciable. All the plates were measured direct and reversed to eliminate personal equation as far as possible.

Radial Velocity Determination. The method of reduction proposed by Professor Curtiss¹⁶ has been followed using the moon as the standard velocity source. For the standard table about forty lines were selected, that were found to be more or less common to stars of Class R and the solar spectrum, and about 25 comparison lines of average intensity well distributed throughout the region λ 3900 to λ 5100.

The first standard table was made from three moon plates with titanium comparison. During the course of the observations the spectrograph was readjusted, which resulted in a change of dispersion sufficient to necessitate a corresponding change in the standard table. Accordingly, the second standard table was prepared by changing the dispersion of the old table to the new by means of a graphical method, plotting the micrometer readings as abscissae and the differences in readings between the old and the new as ordinates. A smooth curve was then formed which together with the scale correction gave the means of conversion. The micrometer readings of the comparison lines in the second standard table are based upon a larger number of measurements than in the first standard table; also a few comparison lines were rejected and others substituted, and a few additional moon lines were included, which were found to be common to Class R stars.

The method of making the lines homogeneous was applied in the case of star — 10° 5057, for which five plates were available. The maximum correction to the computed velocity for a single plate due to this somewhat laborious process was 0.38 km. for plate 2887 A. The small number of plates available for each star and the degree of precision required did not warrant the general adoption of this refinement.

¹⁶ *Astrophysical Jour.*, Vol. 20, p. 149, 1904.

Wave-length Determination. Wave-lengths were determined by means of the Hartmann interpolation formula,

$$\lambda = \lambda_0 + \frac{c}{R_0 - R}.$$

In the determination of the constants of the formula the titanium lines λ 4078.632, λ 4338.081, and λ 4981.916, expressed in Rowland's scale, were used as standard lines in the first standard table. These lines are among the ones selected by Mr. Mellor as standards for "A Study of the Titanium Spark as a Comparison Spectrum in the Single-Prism Spectrograph." The line λ 4163.829 of his list was substituted for λ 4078.632 in the second standard table.

The constants for the first standard table are

$$\begin{aligned} R_0 &= 185.108, \\ \lambda_0 &= 2,204.293, \\ c &= 224,289.5. \end{aligned}$$

For the second standard table the constants are

$$\begin{aligned} R_0 &= 186.184, \\ \lambda_0 &= 2,197.682, \\ c &= 227,282.66. \end{aligned}$$

The residuals, observed wave-length minus computed wave-length, which form the ordinates of the correction curves, are based upon the list of titanium lines given by Mr. Mellor, in these *Publications*, Vol. I, p. 140. The correction curve to accompany the use of the first set of constants is not well determined; but it is more symmetrical than the second, due to the use of standard lines separated by intervals more nearly equal.

Before application of the formulæ

$$\lambda = 2,204.293 + \frac{224,289.5}{185.108 - R}, \quad (1)$$

and

$$\lambda = 2,197.682 + \frac{227,282.66}{186.184 - R}, \quad (2)$$

the micrometer reading, R was corrected for plate velocity. This correction was obtained by multiplying the plate velocity by $\frac{dR}{dv}$, and is applied with the sign changed, since a positive velocity indicates a displacement toward the red or larger

wave-length and the micrometer readings increase in the same direction. After R was corrected for all the plates of a single star the mean value for each line was found, due consideration being given to the quality of the line on the individual plates. This value of R was substituted in the Hartmann formula, the application of which was greatly facilitated by the use of the Millionaire computing machine. The resulting value of the wave-length was corrected by means of the ordinate of the correction curve corresponding to the micrometer reading of the line, which gave the final value of the wave-length. After the wave-lengths of stars $-10^\circ 5057$ and $+57^\circ 702$ had been determined by this method they were used as standards and the difference in R for the other stars was changed into difference in λ by the

factor $\frac{d\lambda}{dR}$ tabulated in the standard table. The application of this difference to the computed wave-length in the standard star gave the value of λ directly, saving much time in computation. These values of the wave-lengths are tabulated for each star in the *Table of Mean Wave-Lengths*.

Degree of Precision. The visual faintness of the stars of Class R and their greater photographic faintness required the use of fast plates, the coarse silver grains of which necessitated a low magnifying power and interfered with precise measurement. The wideness of the slit, usually 0.075 mm., combined with the relatively low dispersion, tended to produce broad lines and blends instead of sharp well-defined slit images. The change in intensity of the lines passing from the moon plates to those of Class R and Class N stars introduce displacements of unknown magnitude. While the shift of ordinary lines with spectral type may not be large between the solar spectrum and spectra of Class R stars, there appears to be a marked change in the position of the center of many measured lines, probably due to the presence of new components or to the unequal change in the relative intensity of the components passing from the solar type to types VI and IV. A few cases that will be pointed out later seem to indicate a systematic shift from star to star passing along the sequence of stars arranged in the order of the intensity of the absorption band. The presence of bright lines also tends to

shift the center of mass of adjacent absorption lines. Error due to this cause was avoided in radial velocity determination by omitting as far as practicable the use of disturbed lines.

The precision of radial velocity determinations is indicated by the tabulated probable errors accompanying the plate velocities, which are based upon the agreement of the velocities given by the lines of the plate. The average for a plate velocity is ± 2.06 km. for the ten Class R stars. The small number of lines on some plates available for comparison with the lines of the standard table accounts for the large average probable error in such cases. The average number of lines used for each plate was 17, giving an average probable error for a single line of 7.18 km., or in wave-lengths

At λ 4000, ± 0.11 Å,

At λ 4500, ± 0.12 Å,

At λ 5000, ± 0.14 Å.

On this basis the probable error of the mean wave-length of a line measured on ten plates is about ± 0.04 Å, and for a line measured on five plates the probable error is about ± 0.06 Å.

After the lines were made homogeneous in the case of star — 10° 5057, for which five plates

were available, the average probable error of the wave-length of a single line was found to be ± 0.050 Å.

MEAN WAVE-LENGTHS

In the table of mean wave-lengths the stars at the head of the columns are arranged in the order of the intensity of the absorption band with head at λ 4737. Under each star are three columns giving respectively the quality, intensity, and computed wave-length of the line. G, F, and P stand for good, fair, and poor, respectively. Occasionally a line is designated as wide (W), very wide (VW), sharp (S), diffuse (Dif.), or nebulous (N or Neb.). Max. stands for the position of maximum intensity in a broad line or band, Str. for the strongest of a group of lines, and Bl. for blend. Br. indicates an emission line. The intensity is estimated on a scale of 10; special difficulties, however, render these estimates approximations only. The last column but one of the table gives the mean wave-lengths of lines common to two or more stars. In general a single star line occupies a single horizontal line of the table, but owing to uncertainties of identification this may not always be the case. The lines of the table are numbered consecutively for convenience of reference.

SPECTRA OF CLASS R STARS

TABLE III. MEAN WAVE-LENGTHS. CLASS R.

NO.	+ 42° 2811.			— 10° 5057.			+ 5° 5223.			+ 20° 5071.			+ 34° 1929.			— 10° 513.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
1	W	5	4188.68	F	5	4187.77	P	3	4187.75	..	..	.....	..	..	.....	..	..	.....
2	..	..	.....	F	2	4191.44	..	..	.....	F	2	4191.96	..	..	.....	..	..	.....
3	P	1	4195.07	W	2	4195.71	P	2	4195.68	..	..	.....	..	..	.....	F	2	4196.16
4	F	2	4196.57	G	3	4196.72	..	..	.....	..	..	.....	..	..	.....	..	..	.....
5	..	..	.....	F	3	4201.83	..	..	.....	..	..	.....	..	..	.....	..	..	.....
6	..	..	.....	..	..	.....	..	..	.....	F	3	4203.00	..	..	.....	..	..	.....
7	W	5	4207.96	W	3	4205.27	F	4	4208.69	F	1	4206.46	..	..	.....	P	2	4207.29
8*	G	10	4215.67	G	10	4215.46	..	..	.....	..	..	.....	..	..	.....	F	7	4215.64
9	Head		4216.59	Head		4216.23	..	..	.....	..	..	.....	..	..	.....	..	..	.....
10	F	3	4218.90	..	..	.....	..	..	.....	P	3	4218.93	..	..	.....	P	3	4218.40
11	..	..	.....	F	3	4220.29	..	..	.....	..	..	.....	P	3	4220.63	..	..	.....
12	P	2	4223.19	F	2	4223.16	..	..	.....	P	2	4223.00	..	..	.....	F	3	4223.28
13	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
14	..	..	.....	..	..	.....	..	..	.....	F	2	4225.89	..	..	.....	..	..	.....
15*	G	10	4227.12	G	7	4227.32	F	8	4227.11	F	7	4227.22	F	7	4227.12	F	7	4227.02
16	Edge		4227.94	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
17	F	2	4230.19	F	1	4230.50	..	..	.....	..	..	.....	..	..	.....	F	2	4229.85
18*	F	4	4233.51	G	6	4233.30	..	..	.....	W	4	4232.92	F	3	4233.91	F	3	4233.34
19*	F	5	4236.51	F	3	4236.31	..	..	.....	..	..	.....	W	4	4236.68	P	3	4236.63
20	..	..	.....	F	4	4239.14	..	..	.....	G	5	4238.58	..	..	.....	..	..	.....
21	Edge		4240.56	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
22	..	..	.....	F	2	4242.60	..	..	.....	..	..	.....	..	..	.....	..	..	.....
23*	F	5	4243.32	..	..	.....	F	3	4243.11	..	..	.....	W	8	4242.99	Bl.	5	4243.47
24	..	..	.....	..	..	.....	..	..	.....	W	5	4244.68	..	..	.....	..	..	.....
25	..	..	.....	G	5	4247.24	..	..	.....	..	..	.....	..	..	.....	..	..	.....
26	..	..	4248.02	..	..	.....	..	..	4248.01	..	..	.....	..	..	4247.87	..	..	4247.86
27*	F	3	4250.44	F	3	4250.46	F	3	4250.76	F	5	4250.49	W	4	4250.86	..	..	4250.86
28	..	..	.....	F	2	4252.65	..	..	.....	..	..	.....	..	..	.....	..	..	.....
29	..	..	.....	..	..	.....	W	3	4254.62	F	3	4254.43	..	..	.....	P	3	4254.56
30	F	4	4255.72	..	..	.....	..	..	.....	..	..	.....	F	2	4255.29	..	..	.....
31	..	..	.....	P	2	4256.48	..	..	.....	..	..	.....	..	..	.....	..	..	.....
32	..	..	.....	..	..	.....	F	3	4257.61	P	2	4257.13	..	..	.....	..	..	.....
33	..	..	4258.94	F	2	4258.47	F	2	4258.70	..	..	.....	..	..	.....	F	3	4259.09
34*	Center		4260.63	F	4	4260.74	..	..	.....	F	3	4260.20	P	5	4260.70	..	..	.....
35	..	..	.....	..	..	.....	F	4	4261.42	Br.	2	4261.46	..	..	.....	..	..	.....
36	..	..	4262.29	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
37	..	..	.....	..	..	.....	..	..	.....	F	2	4263.03	..	..	.....	..	..	.....
38	F	3	4264.83	..	..	.....	..	..	.....	..	..	.....	F	2	4264.38	F	3	4264.64
39	..	..	.....	..	..	.....	..	..	.....	W	5	4266.83	..	..	.....	..	..	.....
40	F	3	4268.28	W	4	4269.12	F	4	4268.29	..	..	.....	..	..	4267.88	F	4	4267.67
41	..	..	.....	..	..	.....	..	..	.....	P	2	4270.44	..	..	.....	..	..	.....
42*	F	5	4271.98	G	4	4271.96	F	3	4271.67	..	..	.....	F	4	4272.02	F	4	4271.79
43	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	F	2	4274.65
44	F	3	4275.21	F	4	4275.26	F	4	4275.01	G	4	4275.86	F	4	4275.48	..	..	
45	F	1	4277.99	F	2	4278.07	..	..		..	..		..	..		..	..	

SPECTRA OF CLASS R STARS

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TABLE III. MEAN WAVE-LENGTHS. CLASS R.

NO.	+ 61° 667.	— 3° 1685.	+ 57° 702.	+ 14° 2048.	MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	ANGSTROMS.	ELEMENT.
1					4187.8	Fe.
2					4191.7	Fe.
3					4195.8	Fe.
4					4196.7	Cy.
5					4201.8	Fe.
6			F 4 4203.01	.. .. .	4203.0	
7						
8*		F 5 4215.43	F 8 4215.69	F 7 4215.81	4215.6	Cy. Fe.?
9			Head 4216.16	Head 4216.43	4216.4	
10					4218.8	Zr.
11		P 3 4220.06	.. .. .	[Br. ? 2 4220.38]	4220.3	Fe.
12				P 2 4223.01	4223.2	
13		Bl. 5 4224.21	.. .. .	.. .. .	.....	
14						
15*		N 5 4227.35	N 7 4227.01	W 10 4227.29	4227.2	Ca. Fe.
16				Edge 4228.11	4228.0	
17		F 2 4229.99	.. .. .	F 1 4230.45	4230.2	Fe.
18		F 3 4233.71	F 3 4233.36	F 3 4233.89	4233.5	Fe.
19		P 3 4236.62	F 4 4237.08	F 4 4237.08	4236.7	
20						
21						
22						
23*	P 3 4243.32	G 4 4243.27	F 4 4243.34	G 5 4243.56	4243.3	Fe.
24						
25						
26			4247.48 }	4248.01 }	.....	
27*		W 3 4250.66	4250.62 }	W 5 4250.66 }	4250.6	Fe, blend.
28				Br. ? 1 4252.78	.....	
29	P 3 4254.62	W 8 4254.95	P 5 4254.90	.. .. .	4254.7	Cr.
30		N 4 4255.70 }	.. .. .	G 10 4255.46	4255.5	Fe. Cr.
31		4256.56 }	.. .. .	.. .. .	.....	
32				[Br. ? 2 4257.82 ]	.....	
33				4258.61 }	4258.8	Fe.
34	P 4 4260.37	W 6 4260.72 }	P 3 4260.57	.. .. .	4260.6	
35		4261.34 }	.. .. .	Str. 4261.07 }	.....	
36				4262.44 }	.....	Fe.
37						
38				F 2 4265.13	4264.7	Fe.
39						
40	F 3 4267.90	F 3 4268.28	.. .. .	4268.66	4268.0 ?	Fe. C.
41						
42*	F 3 4271.49	F 3 4271.85	F 4 4271.85	F 3 4272.24	4271.9	Fe.
43						
44	P 3 4275.14	F 4 4275.16	.. .. .	F 4 4275.33	4275.3	Cr.
45				F 1 4278.28	4278.1	

SPECTRA OF CLASS R STARS

TABLE III. MEAN WAVE-LENGTHS. CLASS R--CONTINUED.

NO.	+ 42° 2811.			— 10° 5057.			+ 5° 5223.			+ 20° 5071.			+ 34° 1929.			— 10° 513.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
46*	G	6	4280.56	F	3	4280.74	G	4	4280.55	..	..	.....	Bl.	5	4280.58	G	5	4280.42
47	..	..	.....	..	..	.....	..	..	.....	G	6	4281.38	..	..	.....	..	..	.....
48	F	1	4283.06	F	2	4282.91	..	..	.....	..	..	.....	..	..	.....	..	..	.....
49	F	4	4286.09	F	2	4286.18	F	3	4286.02	F	5	4286.62	N	3	4286.00	F	4	4285.90
50*	F	3	4289.88	F	6	4290.11	F	3	4289.83	..	..	4290.01	F	4	4290.11	F	3	4289.67
51	F	3	4291.74	..	..	.....	P	2	4291.97	..	..	.....	..	..	.....	..	..	.....
52	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
53	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
54	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	F	2	4294.44
55	S	2	4294.94	F	3	4295.31	F	3	4295.22	..	..	.....	..	..	.....	..	..	.....
56*	F	5	4300.08	G	8	4299.98	F	5	4300.02	..	..	.....	..	..	.....	..	..	.....
57	P	1	4303.04	F	2	4302.93	..	..	.....	..	..	.....	..	..	.....	W	4	4303.52
58	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
59	..	..	.....	F	3	4305.73	..	..	.....	..	..	.....	..	..	.....	..	..	.....
60	..	..	.....	..	..	.....	..	..	.....	..	..	.....	F	5	4306.62	..	..	.....
61	P	2	4308.41	W	5	4308.72	W	4	4308.50	..	..	.....	..	..	.....	..	..	.....
62	..	..	.....	..	..	.....	..	..	.....	..	..	4310.98	..	..	.....	..	..	.....
63*	F	4	4314.47	G	6	4314.69	..	..	4314.62	..	..	.....	F	6	4314.77	F	2	4314.63
64	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	F	2	4317.57
65	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	4318.55	..	..	.....
66	F	1	4319.24	..	..	.....	..	..	.....	W	6	4319.39	..	..	.....	..	..	.....
67	..	..	.....	..	..	.....	F	2	4320.16	..	..	.....	..	..	4320.68	..	..	.....
68	F	1	4321.31	F	4	4321.20	..	..	.....	..	..	.....	..	..	.....	..	..	4321.93
69	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
70	..	..	4324.16	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
71*	G Max.	4325.62	G	7	4325.59	G	10	4324.62	F	3	4324.79	W	6	4325.42	W	8	4324.68	
72	..	4327.29	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	4326.65	
73	..	..	.....	..	..	.....	..	..	.....	F	3	4329.05	..	..	.....	..	..	.....
74	F	2	4330.92	F	4	4330.77	F	3	4330.63	..	..	.....	..	..	.....	F	3	4330.01
75	F	2	4334.42	F	3	4334.12	F	4	4333.93	F	5	4333.33	P	2	4334.21	F	2	4333.44
76*	F	4	4337.91	..	..	4337.72	G	6	4337.88	..	..	.....	F	4	4337.89	F	3	4337.51
77	..	..	.....	F	2	4339.99	..	..	.....	F	2	4339.02	..	..	.....	..	..	.....
78*	F	6	4340.42	..	..	.....	F	3	4340.90	..	..	.....	F	3	4340.54	..	..	4340.34
79	..	..	.....	..	..	.....	..	..	.....	F	3	4342.91	..	..	.....	..	..	.....
80	F	3	4344.26	F	4	4344.40	F	3	4343.97	..	..	.....	F	2	4343.88	P	3	4344.04
81*	F	4	4347.69	F	3	4347.60	F	3	4347.58	G	5	4347.43	F	3	4347.61	G	6	4347.79
82	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
83	..	..	.....	..	..	.....	..	..	.....	F	3	4351.22	..	..	.....	..	..	.....
84*	G	7	4352.11	W	5	4351.67	G	6	4352.01	..	..	.....	F	7	4351.94	F	5	4352.32
85	..	..	.....	..	..	.....	..	..	.....	F	2	4354.71	..	..	.....	..	..	.....
86	F	3	4355.87	F	3	4355.17	F	2	4355.56	..	..	.....	F	4	4355.61	..	..	.....
87	..	..	.....	..	..	.....	..	..	.....	F	2	4358.98	..	..	.....	..	..	.....
88	F	4	4359.78	P	5	4359.41	F	3	4359.76	..	..		F	3	4359.70	..	..	
89	..	..		..	..		..	..		..	..		..	..		..	..	
90	..	..		..	..		..	..		F	3	4362.93	..	..		..	..	

SPECTRA OF CLASS R STARS

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TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61° 667.		— 3° 1685.		+ 57° 702.		+ 14° 2048.		MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		ANGSTROMS.	ELEMENT.
46*	F	3 4280.63	P	3 4280.60	P	4 4280.92	F	4 4280.81	4280.6	Cr.
47	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
48	..	.. .. .	..	.. .. .	..	.. .. .	F	3 4283.08	4283.0	Ti. Ca.
49	..	.. .. .	F	3 4286.31	..	.. .. .	F	4 4286.65	4286.2	Ti.
50*	..	.. .. .	P	3 4290.02	F	3 4289.90	Bl.	4 4289.98	4289.9	Cr. Ca.
51	..	.. .. .	F	3 4291.85	..	.. .. .	F	3 4291.85	4291.8	Fe. Cr.
52	..	.. .. .	..	.. .. .	F	1 4292.43	..	.. .. .	.....	
53	..	.. .. .	..	.. .. .	..	.. .. .	..	4293.95	.....	
54	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
55	..	.. .. .	..	.. .. .	F	1 4295.09	..	.. .. .	.....	
56*	..	.. .. .	F	2 4300.02	..	.. .. .	F	4 4300.13	4300.0	G, Fe, Ti.
57	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
58	..	.. .. .	..	.. .. .	F	3 4304.91	..	.. .. .	.....	
59	..	.. .. .	F	3 4305.86	..	.. .. .	..	.. .. .	.....	
60	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
61	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
62	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
63*	G	3 4314.82	F	3 4314.47	Edge	4315.50	Edge	4315.09	4314.7	Ti. ?
64	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
65	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
66	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
67	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
68	..	.. .. .	..	.. .. .	..	.. .. .	F	2 4321.67	4321.5	
69	..	4323.55	..	.. .. .	..	.. .. .	..	.. .. .	.....	
70	..	.. .. .	..	.. .. .	P	3 4324.18	F	3 4324.12	.....	Ti. Cr.
71*	..	.. .. .	..	.. .. .	F	3 4326.00	..	.. .. .	.....	Fe.
72	..	4326.38	..	.. .. .	..	4327.37	..	.. .. .	.....	
73	..	.. .. .	..	.. .. .	F	3 4329.59	..	.. .. .	.....	
74	F	2 4329.89	F	3 4330.37	..	.. .. .	F	4 4330.13	4330.4	V.
75	P	3 4333.89	W	5 4334.73	..	.. .. .	F	3 4334.65	4334.1	
75*	F	3 4337.81	..	4337.63	P	3 4337.73	..	.. .. .	4337.8	Cr.
77	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
78	P	2 4340.92	..	4340.50	P	2 4340.16	P	2 4341.05	4340.5	Hγ.
79	..	.. .. .	..	.. .. .	F	1 4342.85	..	.. .. .	4342.9	
80	..	.. .. .	..	.. .. .	..	.. .. .	F	3 4343.92	4344.1	Cr. Blend.
81*	W	4 4347.58	..	.. .. .	F	3 4347.77	..	.. .. .	4347.6	
82	..	.. .. .	..	.. .. .	..	.. .. .	F	2 4348.26	.....	
83	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
84	F	6 4352.08	..	.. .. .	F	4 4352.28	..	.. .. .	4352.0	Cr. Mg.
85	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
86	F	4 4355.26	..	.. .. .	..	.. .. .	..	.. .. .	4355.5	Ca.
87	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
88	..	.. .. .	..	.. .. .	F	3 4359.62	..	.. .. .	4359.7	Cr.
89	P	2 4360.49	..	.. .. .	..	.. .. .	..	.. .. .	.....	
90	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	

SPECTRA OF CLASS R STARS

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 28II.			— 10° 5057.			+ 5° 5223.			+ 20° 507I.			+ 34° 1929.			— 10° 513.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
91	W	4	4363.88	W Max.		4363.67	F	4	4363.83	..	..	.....	F	3	4363.49	F	4	4363.31
92			4366.61	..	..	.....	P	2	4366.86	P	3	4366.98	..	..	.....	..	..	.....
93*	P	3	4367.41	P	3	4367.70	..	..	.....	..	..	.....	F	3	4367.90	F	3	4367.17
94	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
95	P	1	4370.39	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
96	..	..	.....	F	4	4371.37	..	..	.....	..	..	.....	..	..	.....	F	4	4371.41
97	..	..	.....	..	..	.....	P	2	4373.25	..	..	.....	..	..	.....	..	..	.....
98	W	5	4374.76	F	6	4374.86	..	..	.....	..	..	.....	..	..	.....	..	..	.....
99	..	..	.....	..	..	.....	F	3	4375.93	..	..	.....	F	4	4375.54	F	4	4376.13
100	P	2	4380.33	P	2	4380.09	..	..	.....	..	..	.....	..	..	.....	..	..	.....
101			4382.95	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
102	G	10	4384.06	..	..	.....	VW	8	4383.84	..	..	.....	G	9	4384.00	F	4	4383.96
103			4385.69	..	..	4385.28	..	..	.....	..	..	.....	..	..	.....	..	..	.....
104	..	..	.....	..	..	.....	..	..	.....	W	3	4386.20	..	..	.....	..	..	.....
105	..	..	.....	F	1	4388.02	F	3	4388.74	..	..	.....	F	2	4388.43	..	..	.....
106	W	4	4389.97	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
107	..	..	.....	F	4	4390.99	F	3	4390.82	..	..	.....	..	..	.....	F	3	4390.26
108	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	4392.25	..	..	.....
109*	F	4	4395.24	G	5	4395.22	G	3	4395.12	F	3	4395.03	F	3	4395.46	G	6	4395.04
110	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
111	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
112*	F	5	4400.82	G	8	4400.52	F	4	4400.47	F	3	4400.69	F	4	4400.77	F	5	4400.37
113	Br.	2	4403.19	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
114*	G	5	4404.89	F	4	4404.67	G	7	4404.87	F	2	4404.79	G	6	4404.84	G	4	4404.78
115	F	4	4408.96	G	7	4408.83	G	6	4408.63	..	..	.....	F	3	4408.98	F	3	4408.63
116	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
117	..	..	.....	P	2	4411.89	..	..	.....	..	..	.....	..	..	.....	..	..	.....
118	Br.	2	4413.04	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
119	..	..	.....	..	..	.....	..	..	.....	Br.	2	4414.24	..	..	.....	..	..	.....
120*	F	6	4415.41	F	4	4415.09	G	6	4415.27	..	..	.....	G	6	4415.56	F	5	4414.97
121	..	..	.....	..	..	.....	..	..	.....	F	3	4416.76	..	..	.....	..	..	.....
122	Edge		4418.22	F	5	4417.94	..	..	.....	..	..	.....	..	..	.....	..	..	.....
123	..	..	.....	..	..	.....	..	..	.....	F	1	4420.17	..	..	.....	..	..	.....
124	F	4	4422.92	F	3	4422.88	F	4	4422.52	..	..	.....	W	4	4422.47	F	3	4422.39
125	..	..	.....	..	..	.....	..	..	.....	W	4	4425.46	N	3	4426.29	..	..	.....
126*	F	3	4430.63	F	4	4430.25	G	4	4430.50	F	5	4430.78	P	3	4430.59	F	4	4430.76
127*	W	8	4435.23	F	6	4435.08	W	4	4435.27	W	1		W	4	4435.25	G	4	4435.28
128	..	..	.....	..	..	.....	..	..	.....	P	4	4437.15	F	1	4437.49	..	..	.....
129	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
130	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
131	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
132*	W	10	4442.99	G	10	4443.37	G	8	4442.66	F	2	4442.80	W	8	4442.97	F	4	4442.00
133	..	..		..	..		..	..		F	3	4445.16	..	..	4444.77	..	..	
134	..	..		..	..		..	..		..	..		..	..		..	..	
135	F	1	4447.46	F	2	4447.37	F	3	4446.92	..	..		..	..		..	..	

SPECTRA OF CLASS R STARS

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TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61° 667.			— 3° 1685.			+ 57° 702.			+ 14° 2048.			MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			ANGSTROMS.	ELEMENT.
91	F	3	4363.53	..	..		..	..		..	..		4363.6	Fe.
92	..	..	.....	..	..	.....	..	..	.....	..	..	.....	4366.9	
93*	G	1	4367.12	..	..	.....	..	..	.....	..	..	.....	4367.6	
94	W	2	4369.05	..	..	.....	..	..	.....	..	..	.....	.....	
95	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
96	..	..		..	..		..	..		..	..		4371.4	Cy. Cr.
97	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
98	..	..		..	..		..	..		..	..		4374.8	Cr. Fe.
99	W	4	4375.36	..	..	.....	F	3	4375.38	..	..	.....	4375.7	
100	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
101	..	..		..	..		..	..		..	..			Fe.
102	W	6	4383.98	F	3	4383.85	P	3	4384.08	F	3	4384.39	4384.1	
103	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
104	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
105	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
106	..	..		..	..		..	..		P	4	4389.59		V. ?
107	F	3	4391.02	..	..	.....	..	..	.....	F	3	4391.15	4390.8	
108	..	..		F	1	4392.40	..	..		..	..			V. Ti.
109*	G	9	4395.01	F	7	4395.07	W	6	4394.67	G	9	4394.73	4395.1	
110	Edge		4395.63	Edge		4396.01	Edge		4395.78	F	4	4395.61	4395.7	
111	..	..		..	..		..	..		Edge		4395.97		Fe. V. ?
112*	F	6	4400.24	F	5	4400.71	F	4	4400.71	G	6	4400.71	4400.6	
113	..	..	.....	Br.	1	4402.57	..	..	.....	Br.	2	4403.21	4403.0	
114*	G	9	4404.95	G Max.		4404.78	G	8	4405.06	[F	7	4405.47]	4404.8	
115	F	6	4408.66	..	..	.....	F	6	4408.70	F	6	4408.85	4408.8	
116	..	..		Edge		4409.58	Edge		4409.00	Edge		4409.47	4409.4	Cr. O in sun.
117	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
118	Rev.	1	4412.15	Rev.	1	4412.86	..	..	.....	F	2	4412.72	.....	
119	..	..		..	..		..	..		..	..			Fe.
120*	G	8	4415.28	G	5	4415.52	F	6	4415.43	G	5	4415.82	4415.4	
121	..	..		..	..		..	..		..	..			Fe. Ti.
122	..	..	.....	G	6	4418.04	..	..	.....	..	..	.....	4418.1	
123	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
124	F	4	4422.40	W	4	4422.60	..	..		F	3	4422.71	4422.6	Fe.
125	..	..		F	1	4426.76	..	..		P	2	4426.10	4426.2	V.
126*	F	3	4430.35	F	4	4430.70	F	3	4430.72	[F	4	4431.13]	4430.6	Fe. Ca.
127*	G	10	4435.68	W Max.		4435.43	G	8	4435.47	G	8	4435.82	4435.4	
128	..	..		..	..		..	..		..	..		4437.4	Fe. Ca.
129	Rev.	1	4438.30	..	..	.....	..	..	.....	..	..	.....	.....	
130	..	..	.....	Br.	2	4439.65	Br.	1	4439.12	Br.	2	4439.21	4439.3	
131	..	..		..	..		..	..		..	..			Fe. Ca.
132*	G	10	4442.77	F	8	4442.80	F	5	4442.79	G	8	4443.26	4443.0	
133	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
134	Br.	2	4445.46	Br.	1	4445.46	Br.	2	4445.79	Br.	2	4446.10	4445.7	Fe. Ca.
135	F	3	4447.04	..	..	.....	F	2	4447.42	F	3	4447.55	4447.3	

SPECTRA OF CLASS R STARS

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 2811.			— 10° 5057.			+ 5° 5223.			+ 20° 5071.			+ 34° 1929.			— 10° 513.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
136	P	2	4450.79	G	6	4450.23	F	3	4450.43	F	3	4450.75	F	3	4449.84	..	..	.....
137	W	4	4455.17	P	2	4454.69	F	3	4455.81	..	..	.....	..	..	.....	F	4	4454.49
138	..	..	.....	P	2	4457.69	..	..	.....	P	2	4457.55	..	..	.....	..	..	.....
139	..	..	.....	..	..	.....	..	..	.....	..	..	.....	F	3	4459.55	..	..	.....
140	..	..	.....	..	..	.....	..	..	.....	Br.	2	4461.37	..	..	.....	..	..	.....
141*	W	5	4461.87	F	4	4461.41	F	4	4461.76	..	..	.....	P	4	4462.12	F	5	4461.74
142	..	..	.....	..	..	.....	..	..	.....	F	3	4463.95	..	..	.....	..	..	.....
143	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
144	..	..	.....	P	3	4464.96	..	..	.....	W	5	4465.14	..	..	.....	..	..	.....
145	P	2	4466.20	..	..	.....	..	..	.....	P	2	4466.06	..	..	.....	..	..	.....
146	F	1	4468.85	F	5	4468.65	..	..	.....	..	..	.....	..	..	.....	..	..	.....
147	F	2	4469.80	..	..	.....	..	..	.....	P	3	4469.46	P	4	4469.57	..	..	.....
148	F	1	4470.76	..	..	.....	P	2	4470.19	..	..	.....	..	..	.....	F	6	4470.75
149	..	..	.....	P	2	4471.78	..	..	.....	..	..	.....	..	..	.....	..	..	.....
150	F	2	4473.58	..	..	.....	..	..	.....	..	..	.....	P	2	4474.82	N	2	4475.86
151*	F	6	4481.39	F	8	4481.11	G	6	4481.58	P	2	4481.73	F	4	4481.30	F	4	4481.48
152	..	..	.....	F	3	4484.35	..	..	.....	..	..	.....	..	..	.....	..	..	.....
153*	F	4	4489.54	F	6	4489.67	P	4	4489.54	F	4	4489.64	F	3	4489.52	..	..	.....
154	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
155	..	..	.....	..	..	.....	..	..	.....	F	2	4491.39	..	..	.....	..	..	.....
156	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
157	..	..	.....	P	3	4494.00	..	..	.....	..	..	.....	..	..	.....	..	..	.....
158	W	4	4495.04	..	..	.....	G	4	4494.67	..	..	.....	W	3	4495.14	F	3	4494.49
159	..	..	.....	P	3	4497.08	..	..	.....	F	3	4496.70	..	..	.....	..	..	.....
160	..	..	.....	..	..	.....	..	..	.....	..	..	.....	F	4	4498.70	F	3	4498.72
161*	F	4	4501.41	G	9	4501.21	F	4	4501.27	F	2	4501.57	G	4	4501.34	F	4	4501.09
162	..	..	.....	Br. ?		4506.92	P	3	4506.45	..	..	.....	..	..	.....	..	..	.....
163	F	3	4507.77	F	3	4508.10	..	..	.....	..	..	.....	..	..	.....	..	..	.....
164	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
165	N	6	4513.97	F	8	4514.19	W	8	4513.79	..	..	.....	F	7	4513.74	G	6	4514.47
166	..	..	.....	..	..	.....	..	..	.....	..	..	.....	P	3	4516.04	..	..	.....
167	..	..	.....	..	..	.....	..	..	.....	F	2	4518.38	..	..	.....	F	3	4518.28
168	..	..	4519.87	F	5	4519.86	F	3	4519.20	..	..	.....	..	..	.....	..	..	.....
169	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
170	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	F	3	4522.29
171	F	2	4523.15	F	4	4522.86	..	..	4523.36	..	..	.....	..	..	.....	..	..	.....
172	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
173	..	..	4525.50	..	..	.....	..	..	.....	..	..	.....	..	..	.....	..	..	.....
174*	F	3	4526.67	P	4	4527.89	..	..	.....	F	4	4526.20	F	3	4526.71	F	4	4526.66
175	Str.		4530.72	P	5	4530.83	W	8	4530.52	..	..	.....	..	..	.....	F	5	4530.82
176	..	..	.....	P	5	4534.36	..	..	.....	..	..	.....	..	..	.....	..	..	.....
177	..	..	4536.43	..	..		..	..	4536.03	..	..		..	..	4536.02	F	3	4536.75
178	..	..		..	..		..	..		..	..		..	..		..	..	
179	..	..		Bl.	3	4540.65	W	4	4540.74	..	..		..	..		..	..	
180	..	..		..	..		..	..		..	..		..	..		F	4	4541.23

SPECTRA OF CLASS R STARS

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TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61° 667.		— 3° 1685.		+ 57° 702.		+ 14° 2048.		MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		ANGSTROMS.	ELEMENT.
136	F	3 4449.83	F	3 4450.41	F	3 4450.21	F	3 4450.61	4450.3	Ti.
137	..	.. .. .	N	4 4455.14	W	3 4455.43	F	4 4455.54	4455.2	Ca.
138	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
139	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
140	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
141*	F	4 4461.79	G	7 4461.74	G	7 4461.74	F	6 4462.10	4461.8	Fe.
142	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
143	Br.	2 4463.40	Br.	2 4464.17	Br.	2 4464.33	Br.	1 4464.01	4464.0	Ti.
144	..	4464.47	..	.. .. .	..	.. .. .	..	.. .. .	.....	
145	F	3 4466.18	..	.. .. .	F	3 4466.09	F	2 4466.66	4466.2	
146	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	4468.7	Ti.
147	..	.. .. .	..	.. .. .	F	3 4469.28	N	5 4469.94	4469.6	Cr. Fe.
148	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	4470.7	Ni.
149	..	4472.02	F	3 4471.21	..	.. .. .	..	4471.50	4471.6	
150	F	4 4475.27	F	3 4475.88	F	4 4476.02	F	3 4476.20	.....	Fe.
151*	P	5 4481.16	N	3 4481.46	W	3 4481.31	N	4 4482.12	4481.4	Ti. Mag.
152	F	3 4484.74	..	.. .. .	..	.. .. .	..	.. .. .	4484.5	Fe.
153*	F	3 4489.82	..	.. .. .	..	.. .. .	..	.. .. .	4489.7	Cr. Fe.
154	..	.. .. .	P	3 4490.24	..	.. .. .	..	.. .. .	.....	
155	..	.. .. .	..	.. .. .	..	.. .. .	F	3 4491.41	4491.4	
156	..	4493.16	..	.. .. .	..	.. .. .	..	.. .. .	.....	
157	..	.. .. .	..	4494.03	..	.. .. .	..	.. .. .	.....	
158	..	.. .. .	..	.. .. .	W	5 4495.09	W	5 4495.34	4495.0	Fe.
159	..	4496.81	..	4496.20	..	.. .. .	..	.. .. .	.....	
160	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	{ N. V.
161*	F	3 4501.51	F	4 4501.32	F	4 4501.30	F	5 4501.88	4501.4	Cr.
162	F	4 4506.67	F	3 4507.28	F	3 4506.83	F	3 4506.96	4506.8	
163	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	4507.9	
164	..	4511.08	..	4511.03	P	3 4511.24	..	4512.37	.....	
165	..	.. .. .	W	8 4514.07	W	6 4514.42	W	9 4514.09	4514.1	Cy.
166	..	4515.08	..	4516.05	..	4515.20	..	4516.66	.....	
167	..	.. .. .	..	.. .. .	..	.. .. .	F	2 4518.33	.....	Ti.
168	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
169	..	.. .. .	..	.. .. .	..	.. .. .	F	2 4520.31	.....	
170	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
171	F	3 4523.20	F	3 4523.11	F	3 4522.76	F	2 4523.27	4523.1	Ti.
172	..	.. .. .	Rev.	1 4524.78	Br.	2 4524.55	..	.. .. .	4524.7	V.
173	..	.. .. .	..	.. .. .	S	1 4525.05	..	.. .. .	.....	Cr.
174*	F	6 4526.67	F	3 4526.92	..	4527.75	F	4 4527.52	4527.0	Ti. Ca.
175	..	.. .. .	..	.. .. .	F	3 4531.71	F	5 4531.42	4531.0	Cr. Fe.
176	F	4 4534.49	..	.. .. .	..	.. .. .	..	.. .. .	.....	Ti.
177	..	4536.05	..	4536.44	..	4537.08	..	4537.06	4536.6	Ti.
178	Br.	1 4537.73	Br.	2 4538.20	..	.. .. .	Br.	3 4538.72	4538.2	
179	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	
180	..	.. .. .	..	.. .. .	..	.. .. .	..	.. .. .	.....	

SPECTRA OF CLASS R STARS

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 28II.		— 10° 5057.		+ 5° 5223.		+ 20° 5071.		+ 34° 1929.		— 10° 513.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.	
181	W	4 4542.20	F	3 4542.18	..	.. .....	..	.. .....	F	3 4541.55	..	.. .....
182	..	.. .....	..	.. .....	..	.. .....	F	4 4544.24	..	.. .....	..	.. .....
183	F	3 4545.20	F	3 4545.44	P	3 4545.54	..	.. .....	F	2 4545.25	F	3 4545.40
184	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....
185	..	.. .....	..	.. .....	..	4546.30	..	.. .....	..	.. .....	..	4548.41
186	..	.. .....	..	.. .....	..	.. .....	W	5 4548.95	..	.. .....	..	.. .....
187*	F	3 4549.86	F	4 4549.61	F	3 4550.09	..	.. .....	F	3 4549.82	P	4 4549.74
188	..	.. .....	..	.. .....	..	4551.96	..	.. .....	Edge	4553.69	F	5 4552.54
189	F	3 4553.47	F	3 4553.48	..	.. .....	..	.. .....	..	.. .....	..	.. .....
190	..	.. .....	..	.. .....	..	.. .....	F	2 4555.27	..	.. .....	..	.. .....
191	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....
192	F	2 4560.77	P	3 4559.96	F	4 4560.38	..	.. .....	P	3 4560.52	F	3 4560.60
193	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....
194	..	.. .....	..	.. .....	..	.. .....	Br.	1 4563.82	..	.. .....	..	.. .....
195*	Var.	4564.93	F	6 4564.65	F	3 4564.68	..	.. .....	W	5 4564.78	..	.. .....
196	..	.. .....	..	.. .....	..	.. .....	F	3 4566.56	..	.. .....	..	.. .....
197	..	.. .....	..	.. .....	..	.. .....	..	.. .....	Br.	1 4567.69	..	.. .....
198	..	.. .....	..	.. .....	..	.. .....	..	.. .....	F	3 4568.95	..	.. .....
199	S	2 4571.85	F	4 4571.81	F	3 4572.26	F	3 4572.23	..	.. .....	P	3 4571.85
200	F	3 4576.73	F	3 4576.85	F	3 4577.02	..	.. .....	W	6 4576.83	F	6 4576.93
201	P	2 4580.20	P	1 4580.82	F	2 4579.86	..	.. .....	F	3 4580.50	F	3 4580.72
202	..	.. .....	F	4 4584.19	F	3 4585.51	..	.. .....	F	5 4585.48	F	3 4586.73
203	..	.. .....	P	3 4587.23	..	.. .....	..	.. .....	..	.. .....	F	2 4588.37
204	..	.. .....	..	.. .....	Br.	2 4589.33	..	.. .....	Br.	1 4590.51	..	.. .....
205	P	3 4592.20	F	2 4592.64	..	.. .....	..	.. .....	..	.. .....	..	.. .....
206	..	.. .....	P	2 4594.80	P	2 4594.33	..	.. .....	..	.. .....	F	2 4593.80
207	F	3 4596.42	..	.. .....	..	.. .....	..	.. .....	..	4596.21	..	.. .....
208	..	.. .....	P	2 4597.03	..	.. .....	F	2 4597.58	..	.. .....	F	2 4597.19
209	..	.. .....	..	.. .....	..	.. .....	Br. ?	2 4599.37	..	.. .....	..	.. .....
210	..	.. .....	F	3 4601.07	..	.. .....	G	4 4601.21	..	.. .....	F	4 4601.53
211	..	.. .....	P	2 4603.34	P	3 4603.21	..	.. .....	..	.. .....	..	.. .....
212	F	4 4605.51	F	5 4605.78	F	4 4605.52	..	.. .....	..	.. .....	F	3 4605.81
213	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	4606.18	..	.. .....
214	..	.. .....	F	4 4612.67	..	.. .....	..	.. .....	..	.. .....	..	.. .....
215	Dif.	3 4613.35	..	.. .....	P	3 4613.25	..	.. .....	..	.. .....	F	3 4613.24
216	..	.. .....	P	3 4614.97	..	.. .....	..	.. .....	..	.. .....	..	.. .....
217	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....
218	F	2 4619.74	F	4 4619.36	F	4 4619.48	..	.. .....	..	.. .....	..	.. .....
219	..	.. .....	F	3 4623.43	..	.. .....	Dif.	2 4624.29	..	.. .....	..	.. .....
220	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....	..	.. .....
221	W	3 4626.03	F	2 4625.99	P	3 4626.20	..	.. .....	..	.. .....	..	.. .....
222	..	.. .....	..	4628.87	F	3 4628.95	..	.. .....	..	.. .....	..	.. .....
223	..		F	4 4629.26	..		..		..		..	
224	W	4 4630.10	F	7 4631.26	..		..		..		..	
225	..		F	6 4633.46	..		..		..		..	

SPECTRA OF CLASS R STARS

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TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61° 667.		— 3° 1685.		+ 57° 702.		+ 14° 2048.		MEAN AND IDENTIFICATION.					
	CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		ANGSTROMS.	ELEMENT.				
181	..	..	N	4	4541.98	F	3	4542.08	F	3	4542.15		V.	
182	..	..	..	..	..	..	..	..	..	..	..	.....		
183	F	3	4545.66	F	3	4545.74	F	5	4545.30	F	3	4546.07		4545.5
184	Br.	2	4547.80	Br.	2	4547.72	..	..	..	..	..	.....		
185	..	..	..	..	..	..	..	..	..	..	..	.....		
186	..	..	..	..	..	..	..	4548.89	..	..	..		V. Ti.	
187*	F	3	4549.74	F	3	4549.50	..	..	..	F	4	4550.13		4549.8
188	..	..	4552.03	..	..	..	..	..	..	..	..	.....		
189	F	10	4552.96	Str.	4552.91	W	7	7452.25	Str.	4552.98	4553.4	Cy.		
190	..	..	4554.58	..	..	4555.00	..	..	4553.76	..	4554.01	4555.		
191	..	..	..	..	4559.51	..	..	..	..	..	..		V.	
192	G	6	4560.42	W	8	4561.60	W	6	4561.43	F	6	4561.11		4560.7
193	..	..	..	..	4563.91	..	..	..	..	..	..	.....		
194	..	..	..	..	..	..	..	..	..	..	..	.....		
195*	Dif.	4	4564.51	..	..	..	..	..	W	3	4565.18	4564.8		
196	..	..	..	F	2	4566.12	..	..	..	..	..		Ti.	
197	Br.	3	4568.00	..	..	..	Br.	1	4567.35	..	..	4567.7		
198	..	..	..	..	..	..	..	..	..	..	..	.....		
199	F	3	4571.87	F	6	4572.00	W	5	4571.95	W	4	4572.00		4571.9
200	F	5	4576.40	F	5	4576.45	W	6	4576.43	F	4	4576.75		4576.7
201	..	..	..	..	..	..	..	..	..	..	..	4580.4	Cr.	
202	F	6	4586.73	F	3	4587.46	W	4	4586.36	W	4	4587.59		Cr.
203	..	..	4587.56	..	..	..	..	..	4588.52	..	..	.....		
204	..	..	..	..	..	..	Br.	2	4591.01	..	..	4589.9		
205	..	..	..	..	..	..	..	..	..	..	..	.....		
206	F	2	4593.62	F	3	4593.30	F	3	4592.97	P	2	4593.63	4593.8	
207	..	..	..	..	..	..	..	..	..	..	..		Cr. ?	
208	..	..	..	..	..	..	..	..	..	F	2	4597.54		4597.3
209	..	..	..	..	..	..	..	..	..	..	..	.....		
210	..	..	4601.51	P	4	4601.12	..	..	..	F	3	4601.41		4601.4
211	..	..	..	..	..	..	..	..	..	W	8	4603.03		4603.2
212	..	..	..	..	..	..	W	6	4605.28	..	..	4605.6	Cy.	
213	..	..	4607.25	..	..	..	..	..	..	..	..	4606.28		
214	..	..	..	..	..	..	..	..	..	..	..		Fe.	
215	F	2	4612.98	..	..	..	..	..	..	..	..	4613.2		
216	..	..	..	W	5	4614.57	W	6	4614.55	F	3	4614.68		4614.7
217	Br.	2	4617.50	..	..	..	..	..	..	..	..	.....		
218	..	..	..	P	3	4620.45	..	..	..	..	..	4619.7		
219	..	..	..	..	..	..	W	4	4623.19	..	..		Ti. V.	
220	..	..	..	..	..	..	..	..	..	F	3	4625.39		
221	..	..	..	..	..	..	..	..	..	..	..	4626.1		Cr.
222	..	..	..	..	..	..	..	..	..	..	..	4628.9		Cr.
223	..	..	..	..	..	..	..	..	..	..	..	.....		
224	..	..	..	..	..	..	..	..	..	..	..		Fe. Cr.	
225	Dif.	7	4633.56	..	..	..	W	5	4632.99	F	4	4633.16		4633.3

SPECTRA OF CLASS R STARS

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 2811.		— 10° 5057.		+ 5° 5223.		+ 20° 5071.		+ 34° 1929.		— 10° 513.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.		CHARACTER, INTENSITY, AND WAVE-LENGTH.	
226	..	..	..	..	..	..	..	..	..	..	F	3 4637.14
227	..	..	F	3 4640.58	F	2 4640.63	W	3 4641.63	..	..	F	2 4640.18
228	..	..	Br.	1 4642.75	..	..	..	..	..	..	..	..
229	P	5 4648.01	F	6 4647.13	W	5 4646.50	..	..	..	..	..	..
230	W	5 4656.55	F	5 4656.52	F	4 4656.54	..	..	..	..	..	..
231	..	..	..	..	..	..	F	2 4658.38	..	..	..	..
232	Br.	4660.01	..	..	..	..	..	..	..	..	..	..
233	..	..	..	..	F	2 4663.23	W	4 4664.73	..	..	..	..
234	W	4 4668.10	..	..	F	4 4668.33	..	..	..	..	..	..
235	Dif.	3 4680.85	..	..	..	..	..	..	..	..	..	..
236	..	..	..	..	P	3 4684.22	..	..	..	..	..	..
237	..	..	..	..	..	..	..	..	..	..	..	..
238	W	3 4696.90	F	4 4696.73	F	4 4698.14	..	..	P	6 4697.34	..	..
239	..	..	..	..	..	..	P	4 4699.05	..	..	..	..
240	..	..	..	..	..	..	G	6 4709.04	..	..	..	..
241	..	..	..	..	..	..	..	..	..	..	..	4713.45 }
242*	F	7 4715.04	F	10 4714.07	G	9 4714.83	..	..	F	6 4715.01	F	6 4714.48 }
243	..	..	..	..	..	..	F	5 4716.87	..	..	..	..
244	F	3 4722.68	..	..	F	4 4722.61	..	..	F	3 4722.37	F	5 4721.61
245	..	..	..	..	..	..	F	2 4724.29	..	..	..	..
246	F	4 4728.83	F	3 4728.77	F	3 4728.79	..	..	F	3 4728.13	F	3 4727.65
247	..	..	..	..	..	..	G	5 4730.93	..	..	..	..
248*	G	4736.36	G	4736.02	G	4636.37	..	..	G	4736.42	G	10 4736.11
249	..	..	..	..	..	..	G	4738.81	..	..	..	..
250	Head	4737.55	Head	4737.47	..	..	..	..	Head	4737.27	Head	4737.07
251	..	..	..	..	..	..	..	..	..	..	..	..
252	W	7 4743.80	..	..	F	6 4743.74	..	..	G	7 4743.65	G	8 4743.66
253	Edge	4745.59	F	2 4745.86	Edge	4744.40	..	..	Edge	4744.66	Edge	4744.80
254	..	..	..	..	..	..	..	..	..	..	..	..
255	F	1 4748.78	..	..	..	..	..	..	..	..	..	..
256	..	..	..	..	..	..	..	..	F	3 4750.62	F	4 4750.99
257	..	..	..	..	..	..	..	..	..	..	..	..
258	F	2 4755.50	F	2 4756.30	..	..	..	..	F	3 4754.94	..	..
259	..	..	..	..	..	..	..	..	F	2 4757.17	..	..
260	..	..	..	..	..	..	..	..	..	..	..	4761.79 }
261	F	1 4762.25	S	2 4762.50	..	..	..	..	..	..	..	..
262	..	..	F	4 4763.78	..	..	..	..	..	4762.97	..	..
263	W	5 4765.13	F	3 4765.46	W	4 4765.96	..	..	W	3 4765.95	W	3 4764.06 }
264	..	..	..	..	..	..	..	..	..	4767.66	..	..
265	..	..	G	3 4771.37	..	..	..	..	..	..	..	..
266	Dif.	2 4772.42	..	..	P	2 4772.18	..	..	..	..	..	4772.33 }
267	..	..	F	2 4775.88	F	3 4775.24	..	..	..	..	..	..
268	..	..	..	..	4780.25	..	..	..	..	..	..	..
269	..	4783.57	P	3 4783.45	..	..	F	2 4783.19	F	3 4784.24	..	..
270	W	5 4787.63	F	3 4786.30	..	..	..	..	..	..	..	..

SPECTRA OF CLASS R STARS

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TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61° 667.			— 3° 1685.			+ 57° 702.			+ 14° 2048.			MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			ANGSTROMS.	ELEMENT.
226	F	3	4637.16	P	3	4636.68	..	..		..	..		4637.0	Ca.
227	F	3	4640.64	..	..	.....	..	..	.....	..	..	.....	4640.7	
228	Br.	2	4643.08	..	..		..	..		..	..		4642.9	Ti. Cr.
229	..	..	.....	..	..	.....	..	..	.....	F	3	4645.96	.....	
230	..	..	.....	F	3	4656.88	..	..	.....	..	..	.....	4656.6	
231	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
232	..	..		..	..		..	..		..	..			Fe.
233	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
234	..	..	.....	..	..	.....	..	..	.....	..	..	.....	4668.2	
235	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
236	..	..		..	..		..	..		..	..			C.
237	F	4	4694.24	..	..	.....	..	..	.....	..	..	.....	.....	
238	..	..	.....	..	..	.....	..	..	.....	..	..	.....	4697.2	
239	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
240	..	..		..	..		..	..		..	..			C. Ni.
141	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
242*	F	6	4715.18	..	..	.....	..	..	.....	..	..	.....	4714.8	
243	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
244	F	6	4722.43	..	..		..	..		..	..		4722.3	Zn.
245	..	..		..	..		..	..		..	..			Fe.
246	..	..	.....	P	3	4729.17	..	..	.....	..	..	.....	4728.6	
247	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
248*	F	6	4736.62	F	6	4736.59	F	6	4736.56	W	6	4736.90	4736.4	
249	..	..		..	..		..	..		..	..			Cr.
250	Head		4737.70	Head		4737.67	..	..	.....	Head		4737.92	4737.6	
251	Br.	3	4739.71	..	..	.....	..	..	.....	Br.	2	4739.61	4739.7	
252	G	10	4743.60	G	10	4743.17	G	10	4743.20	G	10	4743.60	4743.6	
253	Edge		4745.40	Edge		4745.11	Edge		4745.14			4745.14	4745.1	..
254	Br.	2	4747.63	Br.	3	4747.46	..	..	.....	Br.	3	4747.78	4747.6	
255	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
256	F	6	4751.51	G	10	4751.02	G	10	4751.05	G	9	4751.51	4751.1	
257	Edge		4753.31	Edge		4752.45	Edge		4752.91	Edge		4752.51	4752.8	..
258	..	..	.....	Br.	3	4755.32	..	..	.....	..	..	.....	.....	
259	..	..	.....	F	3	4758.38	F	2	4757.83	F	2	4758.58	4758.0	
260	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
261	..	..		..	..		..	..		..	..		4762.4	..
262	..	..	.....	..	..	.....	..	..	.....	..	..	.....	.....	
263	..	..	.....	..	..	.....	..	..	.....	..	..	.....	4765.3	
264	Neb.		4766.51	F	3	4765.98	W	3	4764.79	P	2	4765.92	.....	
265	..	..		..	..		..	..		..	..			..
266	F	3	4772.30	F	2	4772.30	F	2	4772.30	P	3	4772.91	4772.4	
267	Br.	2	4777.85	..	..	.....	Br.	2	4775.26	..	..	.....	.....	
268	..	..	4780.15	..	..	.....	..	..	.....	..	..	.....	.....	
269	..	..		..	..		F	3	4784.77	..	..			..
270	Neb.	4	4787.23	W	5	4787.02	..	..	.....	F		4786.65	.....	

SPECTRA OF CLASS R STARS

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 2811.	— 10° 5057.	+ 5° 5223.	+ 20° 5071.	+ 34° 1929.	— 10° 513.
	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.
271	4793.17	P 3 4792.40	4792.04	.. .. .	.. .. .	F 3 4793.59
272	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
273	F 3 4799.52	F 3 4799.09	F 4 4799.40	.. .. .	F 3 4799.42	.. .. .
274	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	W 3 4801.28
275	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
276	.. .. .	P 3 4804.80	.. .. .	.. .. .	.. .. .	.. .. .
277	Dif. 3 4807.86	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
278	4809.90	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
279	.. .. .	P 2 4811.78	.. .. .	.. .. .	.. .. .	.. .. .
280	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
281	.. .. .	P 3 4817.03	.. .. .	.. .. .	.. .. .	.. .. .
282	.. .. .	.. .. .	.. .. .	P 2 4818.90	.. .. .	.. .. .
283	.. .. .	.. .. .	F 3 4823.74	.. .. .	.. .. .	F 2 4822.73
284	W 3 4824.05	P 3 4824.72	.. .. .	.. .. .	.. .. .	.. .. .
285	.. .. .	P 3 4826.66	.. .. .	.. .. .	.. .. .	.. .. .
286	.. .. .	P 2 4828.89	.. .. .	.. .. .	.. .. .	.. .. .
287	P 3 4833.00	.. .. .	F 3 4833.08	.. .. .	.. .. .	.. .. .
288	.. .. .	F 4 4836.83	F 3 4838.60	.. .. .	F 3 4838.18	F 3 4839.31
289	Dif. 3 4841.41	.. .. .	.. .. .	.. .. .	F 3 4841.94	P 4 4841.77
290	.. .. .	P 2 4843.75	.. .. .	.. .. .	.. .. .	F 1 4844.14
291	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
292	F 2 4848.64	F 3 4848.76	F 3 4848.86	.. .. .	.. .. .	.. .. .
293	F 4 4855.85	F 4 4855.05	.. .. .	G 5 4856.32	P 2 4855.54	F 2 4855.86
294*	G 5 4861.39	.. .. .	F 4 4860.60	F 1 4861.34	F 2 4861.26	F 5 4861.42
295	.. .. .	P 2 4865.81	.. .. .	F 2 4866.64	Br. 1 4866.67	.. .. .
296	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	F 2 4868.40
297	4870.29	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
298*	.. .. .	F 4 4871.41	F 4 4871.88	F 2 4871.67	Dif. 3 4872.31	F 2 4872.08
299	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
300	.. .. .	P 3 4875.54	.. .. .	.. .. .	.. .. .	.. .. .
301	4877.14	.. .. .	.. .. .	.. .. .	.. .. .	F 3 4877.95
302	.. .. .	F 3 4881.29	.. .. .	.. .. .	.. .. .	.. .. .
303	4884.60	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
304*	W 3 4886.07	F 4 4886.23	F 3 4886.10	W 4 4886.12	F 5 4885.95	F 4 4886.49
305	.. .. .	P 2 4889.28	.. .. .	.. .. .	.. .. .	.. .. .
306	4892.80	.. .. .	F 3 4892.05	.. .. .	Dif. 4 4892.60	F 3 4892.05
307	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
308	.. .. .	.. .. .	.. .. .	F 3 4896.82	.. .. .	.. .. .
309	.. .. .	F 3 4900.79	.. .. .	.. .. .	G 4 4900.14	.. .. .
310	.. .. .	.. .. .	F 2 4903.43	.. .. .	.. .. .	.. .. .
311	.. .. .	.. .. .	.. .. .	F 3 4905.54	.. .. .	.. .. .
312	F 3 4911.07	F 4 4910.69	F 3 4911.12	.. .. .	.. .. .	.. .. .
313	.. .. .	.. .. .	.. .. .	P 4 4915.81	.. .. .	.. .. .
314	4917.85	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
315	Str. 4920.98	G 7 4922.32	G 4 4920.58		F 4 4921.70	F 4 4920.67

SPECTRA OF CLASS R STARS

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TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61° 667.	— 3° 1685.	+ 57° 702.	+ 14° 2048.	MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	ANGSTROMS.	ELEMENT.
271	4792.20]	F 2 4793.53 ]	.. .. .	.. .. .	.....	
272	Br. 2 4795.21	.. .. .	.. .. .	.. .. .	.....	
273	W 4 4799.34	F 4 4798.99	F 3 4798.84	W 3 4799.64	4799.3	
274	.. .. .	.. .. .	.. .. .	.. .. .	.....	
275	Br. 2 4803.00	.. .. .	.. .. .	.. .. .	.....	
276	.. .. .	W 2 4805.81	.. .. .	.. .. .	.....	
277	.. .. .	.. .. .	.. .. .	.. .. .	.....	
278	.. .. .	.. .. .	.. .. .	.. .. .	.....	
279	F 3 4811.45	Br. 1 4811.23	.. .. .	.. .. .	4811.5	
280	.. .. .	F 2 4816.46	.. .. .	F 3 4816.50	4816.5	
281	.. .. .	.. .. .	.. .. .	.. .. .	.....	
282	Br. 2 4818.15	Br. 2 4819.32	Br. 2 4818.72	Br. 3 4820.22	.....	
283	F 4 4823.28	F 4 4822.57	F 2 4822.70	F 4 4822.52	4822.9	
284	.. .. .	.. .. .	.. .. .	.. .. .	.....	
285	.. .. .	.. .. .	.. .. .	.. .. .	.....	
286	.. .. .	F 2 4827.16	F 2 4828.32	F 3 4828.58	4828.2	V.
287	F 4 4832.57	F 2 4832.19	F 2 4833.24	F 2 4833.00	4832.8	Fe.
288	.. .. .	G 5 4839.40	.. .. .	.. .. .	.....	
289	F 3 4842.89	.. .. .	.. .. .	.. .. .	.....	
290	.. .. .	G 6 4843.10	F 3 4843.69	F 3 4843.38	4843.6	
291	.. .. .	W 4 4845.58	.. .. .	.. .. .	.....	
292	F 2 4848.78	.. .. .	.. .. .	S 2 4847.72	4848.6	
293	F 3 4855.64	F 4 4854.46	F 3 4854.74	P 2 4854.95	4855.4	
294*	W 3 4861.14	W 5 4860.91	F 3 4861.38	W 4 4862.35	4861.3	H β .
295	S 1 4865.68	.. .. .	P 2 4866.58	.. .. .	.....	Ni. ?
296	.. .. .	.. .. .	Br. 2 4868.62	.. .. .	.....	
297	.. .. .	.. .. .	.. .. .	.. .. .	.....	
298*	.. .. .	P 2 4871.77	F 1 4872.15	.. .. .	4871.9	V. Fe.
299	F 3 4875.15	.. .. .	.. .. .	.. .. .	.....	
300	.. .. .	F 3 4876.25	F 4 4875.90	F 3 4875.77	4875.7	V.
301	.. .. .	.. .. .	.. .. .	.. .. .	.....	
302	.. .. .	F 3 4881.34	F 3 4881.09	F 2 4881.25	4881.2	V. ?
303	.. .. .	.. .. .	.. .. .	.. .. .	.....	
304*	W 4 4886.29	F 3 4886.23	F 4 4886.20	G 3 4886.57	4886.2	Fe. V.
305	.. .. .	.. .. .	.. .. .	.. .. .	.....	
306	F 5 4891.51	F 4 4891.01	F 2 4890.85	.. .. .	.....	V.
307	Edge 4892.13	.. .. .	.. .. .	.. .. .	.....	
308	Br. 2 4896.52	.. .. .	F 3 4896.78	.. .. .	.....	
309	.. .. .	Br. 2 4898.29	.. .. .	Br. 2 4899.51	.....	
310	F 5 4902.89	F 3 4901.69	F 3 4901.08	.. .. .	.....	
311	.. .. .	F 3 4905.74	F 2 4906.64	.. .. .	4906.0	V.
312	.. .. .	F 4 4910.97	W 4 4911.33	F 4 4910.91	4911.0	Fe.
313	.. .. .	.. .. .	.. .. .	.. .. .	.....	
314	.. .. .	.. .. .	.. .. .	.. .. .	.....	
315	G 5 4920.12	G 7 4921.31	W 5 4919.72	F 4 4921.64	4921.0	Fe.

SPECTRA OF CLASS R STARS

TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 42° 28II.	— 10° 5057.	+ 5° 5223.	+ 20° 5071.	+ 34° 1929.	— 10° 513.
	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.
316	4926.11 J	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
317	.. .. .	F 3 4933.77	.. .. .	F 6 4931.06	.. .. .	.. .. .
318	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
319	W 4 4939.01	P 4 3937.84	P 2 3940.21	.. .. .	.. .. .	F 4 3938.19
320	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
321	F 4 4957.86	F 3 4957.77	F 4 4958.20	.. .. .	.. .. .	.. .. .
322	.. .. .	.. .. .	F 3 4965.73	.. .. .	.. .. .	.. .. .
323	Dif. 2 4969.74	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
324	.. .. .	.. .. .	F 2 4978.07	.. .. .	.. .. .	.. .. .
325	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .	.. .. .
326	W 5 4984.09	G 4 4983.19	F 4 4984.06	F 5 4985.68		P 3 4984.96
327						
328						
329	F 4 5006.89		F 3 5006.70			

SPECTRA OF CLASS R STARS

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TABLE III. MEAN WAVE-LENGTHS. CLASS R—CONTINUED.

NO.	+ 61° 667.	— 3° 1685.	+ 57° 702.	+ 14° 2048.	MEAN AND IDENTIFICATION.	
	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	CHARACTER, INTENSITY, AND WAVE-LENGTH.	ANGSTROMS.	ELEMENT.
316						Fe.
317		F 2 4929.76	.. .. .	.. .. .	.....	
318		F 2 4932.25	.. .. .	.. .. .	.....	
319		F 6 3936.63	W 4 3937.69	W 4 3935.74	.....	
320		3954.39	.. .. .	.. .. .	.....	
321				W 3 4958.94	4958.2	
322						
323		4968.77	.. .. .	F 3 4968.38	.....	
324		W 6 4977.62	F 4 4977.85	.. .. .	4977.8	
325		Rev. I 4982.08	Br. 1 4982.22	.. .. .	4982.1	
326		F 6 4985.74	F 6 4986.63	W 5 4987.49	.....	
327		4990.65	.. .. .	.. .. .	.....	
328		F 3 5000.61	F 5 5001.20			Ti. Fe. Ti.
329						

SPECTRA OF CLASS R STARS

TABLE IV. WAVE-LENGTHS. CLASS N.

NO.	19 PISCUM.			+ 76° 734.			+ 34° 4500.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
1	End		4242.98	..	..	.....	..	..	.....
2	P	5	4247.68	..	..	.....	..	..	.....
3	F	1	4251.08	..	..	.....	..	..	.....
4	P	5	4254.12	..	..	.....	..	..	.....
5	P	6	4258.86	..	..	.....	..	..	.....
6	P	2	4260.69	..	..	.....	..	..	.....
7	F	5	4262.94	..	..	.....	..	..	.....
8	F	4	4271.91	..	..	.....	..	..	.....
9	F	6	4275.41	..	..	.....	..	..	.....
10	F	4	4277.70	..	..	.....	..	..	.....
11	Br.	2	4278.74	..	..	.....	..	..	.....
12	F	3	4280.81	..	..	.....	..	..	.....
13	F	3	4283.10	..	..	.....	..	..	.....
14			4288.52	..	..	.....	..	..	.....
15	F	6	4289.37	..	..	.....	..	..	.....
16	F	3	4291.90	..	..	.....	..	..	.....
17			4292.50	..	..	.....	..	..	.....
18	F	3	4294.93	..	..	.....	..	..	.....
19	G	6	4307.00	F	6	4306.70	P	5	4307.39
20	F	3	4319.04	F	4	4318.82	..	..	.....
21	P	3	4321.51	..	..	.....	..	..	.....
22	G	10	4325.47	..	..	.....	F	7	4325.59
23	F	3	4330.13	..	..	.....	..	..	.....
24	P	3	4333.85	..	..	.....	P	4	4334.05
25	F	2	4337.76	P	4	4338.28	F	5	4339.22
26	Br. ?		4339.62	..	..	.....	..	..	.....
27	F	2	4341.70	..	..	.....	..	..	.....
28	..	..		..	..	.....	P	3	4346.22
29	G	3	4348.06	F	4	4347.53	F	4	4347.98
30	G	8	4351.90	..	..	.....	F	6	4351.96
31	F	3	4355.97	..	..	.....	..	..	.....
32	F	9	4360.46	..	..	.....	W	5	4360.38
33			4365.16	..	..	.....	..	..	.....
34	F	6	4368.48	..	..	.....	W	5	4368.37
35	F	1	4373.13	..	..	.....	..	..	.....
36	F	3	4376.09	F	4	4375.78	F	4	4375.94
37	Br.	1	4377.98	..	..	.....	..	..	.....
38	F	5	4380.64	..	..	.....	..	..	.....
39	G	7	4384.50	F	8	4384.21	..	..	.....
40	..	..				4385.27	Head		4385.42
41	..	..	.....	G	3	4387.44	..	..	.....
42	F	4	4390.27	F	5	4390.04	F	4	4390.44
43	G	8	4395.01	F	7	4394.99	F	7	4394.86
44	..	..	.....	..	..	.....	Br.		4402.62
45	F	5	4400.56	F	6	4400.30	F	8	4400.29

TABLE IV. WAVE-LENGTHS. CLASS N—CONTINUED.

NO.	19 PISCUM.			+ 76° 734.			+ 34° 4500.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
46	G	6	4404.92	G	8	4404.86	F	7	4405.19
47	F	5	4408.62	F	6	4408.47	F	5	4408.64
48	P	2	4412.61	F	3	4412.01	..	..	.....
49	F	4	4415.31	..	..	.....	F	4	4415.53
50	..	..	.....	P	6	4416.37	..	..	.....
51	F	4	4417.34	..	..	.....	..	..	.....
52	F	3	4420.95	..	..	.....	..	..	.....
53	..	..	.....	F	6	4422.26	F	5	4422.16
54	P	2	4423.21	..	..	.....	..	..	.....
55	F	1	4426.10	..	..	.....	..	..	.....
56	F	3	4428.00	..	..	.....	G	4	4427.65
57	F	3	4430.05	F	4	4429.74	F	3	4430.33
58	Br.	1	4432.34	..	..	.....	Br.		4432.71
59	G	7	4435.46	G	10	4435.48	G	8	4435.72
60	..	..	.....	..	..	.....	F	2	4438.59
61	..	..	.....	..	..	.....	Br.		4439.56
62	F	4	4443.43	W	7	4444.03	W	6	4443.08
63	..	..	.....	..	..	.....	F	2	4447.44
64	F	4	4450.36	F	6	4450.25	G	5	4450.40
65	F	4	4455.80	P	6	4455.20	P	4	4455.98
66	F	2	4459.72	..	..	.....	..	..	.....
67	F	4	4462.04	F	7	4462.11	F	6	4462.11
68	Br.		4463.95	..	..	.....	Br.		4464.33
69	F	2	4465.70	F	5	4465.86			4465.61
70	P	3	4468.64	F	4	4468.84	..	..	.....
71	P	3	4471.50	..	..	.....	..	..	.....
72	..	..	.....	..	..	.....			4472.21
73	..	..	.....	..	..	.....	Br.		4473.04
74	P	3	4476.39	F	4	4476.18	..	..	.....
75	P	4	4480.23	F	7	4480.53	F	7	4480.39
76	..	..	.....	..	..	.....	F	3	4487.47
77	F	4	4489.60	P	6	4489.18	F	4	4489.58
78	F	1	4493.80	F	2	4494.50	..	..	.....
79	G	6	4496.97	G	6	4496.83	G	7	4496.92
80	F	3	4501.51	F	4	4501.65	F	5	4501.44
81	Br.		4501.81	..	..	.....	Edge		4501.90
82	G	4	4506.88	F	5	4506.81	F	5	4507.00
83	P	4	4513.04	F	6	4512.83	W	6	4513.70
84	F	3	4518.47	P	5	4518.63	F	3	4518.63
85	..	..	.....	F	2	4520.10	..	..	.....
86	F	3	4523.30	G	5	4522.97	G	4	4523.30
87	..	..	.....	..	..	.....			4526.06
88	F	4	4527.87	F	6	4527.31	P	6	4528.17
89	P	2	4531.45	..	..	.....	..	..	.....
90	P	5	4535.47	G	8	4535.28	..	..	.....

SPECTRA OF CLASS R STARS

TABLE IV. WAVE-LENGTHS. CLASS N—CONTINUED.

NO.	19 PISCUM.			+ 76° 734.			+ 34° 4500.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
91	..	..	.....	..	..	.....	Edge		4536.34 J
92	Br.	2	4538.14	..	..	.....	..	..	.....
93	G	4	4540.71	F	5	4540.95	F	5	4541.27
94	F	3	4545.81	F	4	4545.74	G	5	4545.93
95	..	..	.....	G	3	4549.11	..	..	.....
96	F	3	4549.72	..	..	.....	F	6	4549.93
97	G	10	4553.85	F	9	4553.34	G	10	4553.61
98	P	3	4560.04	F	4	4560.26	F	3	4560.16
99	P	3	4563.44	..	..	.....	F	4	4563.39
100	W	4	4564.68	P	4	4564.06	..	..	.....
101	F	1	4565.10	..	..	.....	..	..	.....
102	..	..	.....	..	..	4570.34	..	..	.....
103	..	..	.....	..	..	.....	..	..	4571.12
104	..	..	4571.92	..	..	.....	..	..	.....
105	..	..	4576.78	..	..	4577.20	..	..	4578.26
106	..	..	.....	F	4	4590.86	..	..	.....
107	..	..	.....	F	2	4593.94	F	4	4593.74
108	..	..	.....	F	1	4597.37	F	3	4598.10
109	..	..	.....	P	2	4600.58	..	..	.....
110	..	..	.....	F	1	4603.18	..	..	.....
111	G	10	4606.72	G	10	4606.60	G Max.		4606.25
112	..	..	.....	F	1	4610.45	..	..	.....
113	..	..	.....	F	2	4613.45	F	4	4613.75
114	F	2	4616.48	F	2	4616.22	F	4	4616.84
115	F	3	4619.96	G	4	4619.52	G	6	4620.06
116	..	..	.....	..	..	.....	F	3	4623.12
117	F	3	4629.38	W	4	4629.12	F	4	4629.56
118	..	..	4632.61	..	..	.....	..	..	4632.14
119	..	..	.....	W	6	4635.30	..	..	.....
120	..	..	4637.35	..	..	.....	..	..	4637.59
121	G	5	4640.47	G	5	4640.29	G	6	4640.65
122	Br.	2	4642.22	..	..	.....	Br.		4642.67
123	..	..	.....	..	..	4644.03	..	..	4644.11
124	W	7	4646.55	F	8	4646.28	..	..	.....
125	F	6	4656.94	F	6	4657.18	F	5	4657.15
126	W	5	4663.34	..	..	.....	F	3	4663.55
127	W	7	4668.85	F	5	4668.04	F	6	4668.77
128	..	..	.....	F	4	4682.27	..	..	.....
129	..	..	.....	..	..	.....	W	8	4695.78
130	..	..	.....	..	..	4698.21	..	..	.....
131	F	3	4704.04	F	3	4704.40	..	..	.....
132	P	4	4707.42	..	..	.....	..	..	.....
133	G	9	4714.62	F	8	4714.43	G	10	4714.14
134	F	2	4722.97	F	6	4722.83	F	3	4722.88
135	F	3	4729.43	..	..	.....	..	..	.....

TABLE IV. WAVE-LENGTHS. CLASS N—CONTINUED.

NO.	19 PISCUM.			+ 76° 734.			+ 34° 4500.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
136	G	10	4735.96	G	10	4735.87	G	10	4735.96
137	Head		4736.82	Head		4737.11	..	..	.....
138	F	6	4743.79	G	9	4743.52	G	10	4743.76
139	..	..	.....	F	4	4745.67	..	..	.....
140	..	..	.....	F	2	4758.67	..	..	.....
141	..	..	.....	F	1	4761.49	F	2	4763.52
142	..	..	.....	F	4	4772.43	P	2	4773.29
143	..	..	.....	F	3	4779.34	..	..	.....
144	..	..	.....			4782.33	..	..	.....
145	Neb.		4784.59	W	5	4784.75	..	..	.....
146	..	..	.....			4789.54	P	2	4789.45
147	..	..	.....	F	3	4791.18	..	..	.....
148	..	..	.....	Dif.	4	4799.69	..	..	.....
149	..	..	.....	P	3	4805.75	W	4	4806.84
150	..	..	.....	..	..	.....	F	2	4812.13
151	F	2	4816.03	G	4	4815.82	F	3	4816.24
152	P	2	4823.50	F	5	4822.80	F	4	4823.44
153	..	..	.....	F	4	4827.82	F	3	4828.36
154	P	2	4832.72	F	5	4832.54	G	3	4833.00
155	..	..	.....	F	3	4839.82	..	..	.....
156	..	..	.....	P	2	4848.93	..	..	.....
157	..	..	.....	F	3	4852.18	..	..	.....
158	..	..	.....	F	4	4854.78	P	4	4854.28
159	Head		4855.37	..	..	.....	..	..	.....
160	..	..	.....	W	4	4865.66	F	3	4865.47
161	..	..	.....	..	..	.....	F	2	4868.48
162	F	2	4871.74	..	..	.....	F	3	4872.02
163	P	2	4874.92	F	4	4875.54	F	3	4876.03
164	F	2	4881.46	G	4	4881.74	F	3	4882.13
165	F	1	4885.40	..	..	.....	..	..	.....
166	..	..	.....	P	4	4891.02	W	4	4891.43
167	..	..	.....	F	3	4900.72	..	..	.....
168	..	..	.....	..	..	.....	F	4	4902.77
169	..	..	.....	P	3	4905.33	..	..	.....
170	..	..	.....	F	2	4910.28	..	..	.....
171	..	..	.....	P	4	4914.40	..	..	.....
172	Red Edge		4914.50	..	..	.....	..	..	.....
173	F	3	4921.44	G	4	4920.73	G	6	4921.12
174	F	4	4934.35	F	4	4934.22	F	6	4934.64
175	P	3	4940.12	..	..	.....	..	..	.....
176	..	..	.....	..	..	.....	F	3	4950.18
177	..	..	.....	P	4	4957.16	F	3	4958.57
178	..	..	.....	F	4	4966.86	..	..	.....
179	P	4	4981.39	F	5	4980.33	P	2	4982.35
180	..	..	.....	F	4	4986.42	..	..	.....

SPECTRA OF CLASS R STARS

TABLE IV. WAVE-LENGTHS. CLASS N—CONTINUED.

NO.	19 PISCUM.			+ 76° 734.			+ 34° 4500.		
	CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.			CHARACTER, INTENSITY, AND WAVE-LENGTH.		
181	W	5	4988.20	..	..	.....	..	..	.....
182	..	..	.....	F	4	4990.08	..	..	.....
183	W	5	5006.56	F	4	4999.63	F	4	5000.70
184	F	4	5014.76	F	5	5014.44	F	3	5014.62
185	..	..	.....	F	6	5038.96	..	..	.....
186	Red Edge		5041.30	..	..	.....	..	..	.....
187	..	..	.....	F	7	5095.29	..	..	.....
188	..	..	.....	Red Edge		5167.95	..	..	.....
189	..	..	.....	F	6	5182.71	..	..	.....
190	..	..	.....	F	3	5192.91	..	..	.....
191	..	..	.....	W	8	5205.82	..	..	.....

RADIAL VELOCITIES

The accompanying table (Table V) of radial velocities contains the results obtained for 10 stars belonging to Class R. Although the list is not large enough to give more than an indication of the average radial velocity of the class, it furnishes the only data available at the present time.

Column 1 gives the star's designation; column 2, the plate numbers. The third column gives the quality of the stellar spectrum, S, and of the comparison spectrum, C, of the plate; G, good; F, fair; P, poor; W, wide; and Dif., diffuse. Column 4 contains the number of the lines used in each plate. The radial velocities determined from the individual plates and reduced to the sun are recorded in column 5, also the probable error based upon the internal agreement of the velocities given by the lines used in the reduction of the plate. Column 6 gives the adopted radial velocity of the star reduced to the sun and its probable error. The last column tabulates the residual radial velocity after deducting the component due to the motion of the sun through space, or the radial velocity of the star reduced to the sidereal system.

The number of lines for radial velocity determination of star — 10° 5057 recorded in the table is smaller than the number available for use on the individual plates, as only the lines giving the best results on all the plates were included. Making use of 27 lines of plate 2882 A, 30 lines of

plate 2997 A, 31 lines of plate 2914 A, and 32 lines of plate 2915 A, the result gives practical agreement with the value given in the table. The star + 20° 5071 presented some difficulty on account of its broad absorption lines and the presence of bright lines near some of the lines of the standard table. The probable error of the velocity of this star indicates that the close agreement of the separate velocities derived from the three plates is in a measure fortuitous. The relative velocity of this star with reference to — 10° 5057 was determined by comparing the displacements of 20 lines in common and gave good agreement with the tabulated values.

The radial velocity for each star was obtained by weighting the plate velocities according to probable error and the quality of the plate. On account of the small number of available plates for each star, the probable error accompanying the adopted value of the radial velocity of the star was based upon the internal agreement of the lines of the individual plates instead of following the ordinary method of forming residuals from the mean velocity. For the determination of the residual radial velocities the apex of the sun's way was taken at the point, $\alpha = 270^\circ$, $\delta = +30^\circ$, and the velocity of the sun with reference to the sidereal system was taken to be 20 km. per sec. This is the position of the apex of the sun's way and value of the velocity of the sun through space favored by Boss for general use

SPECTRA OF CLASS R STARS

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TABLE V. RADIAL VELOCITIES, CLASS R.

STAR.	PLATE.	QUALITY.		NO. OF LINES.	PLATE VELOCITY TO SUN.	STAR VELOCITY TO SUN.	RESIDUAL RADIAL VELOCITY.
		S.	C.				
DM. + 42° 2811	3128 B	F	F	32	-24.5 ± 1.3		
	3135 B	G	F	33	-26.0 ± 1.0		
	3144 B	G	G	37	-25.2 ± 1.2	-25.2 ± 0.8	- 6.
— 10 5057	2882 A	G	F	17	-43.2 ± 1.7		
	2887 A	G	G	18	-42.5 ± 1.3		
	2914 A	G	G	20	-42.6 ± 1.3		
	2915 A	G	G	21	-45.0 ± 0.6		
	2923 A	P	F	14	-43.6 ± 4.3	-43.8 ± 0.5	- 30.
+ 5 5223	2988 A	F	G	26	-26.0 ± 1.5		
	2989 B	F	F	26	-26.4 ± 2.2	$-26. \pm 1.1$	- 24.
+ 20 5071	2966 C	F	G	19	-40.8 ± 1.6		
	Remeasured.				-48.4 ± 2.2		
	2967 A	D	F	12	-48.8 ± 5.2		
	2968 A	P	F	14	-50.1 ± 4.1	$-49. \pm 2.$	- 38.
+ 34 1929	3138 B	F	P	33	$+27.8 \pm 1.6$		
	3143 A	W	G	26	$+22.6 \pm 1.5$	$+25. \pm 1.$	+ 20.
— 10 513	3055 A	P	F	12	$+21.9 \pm 3.9$		
	3063 A	F	G	24	$+19.8 \pm 1.2$	$+21. \pm 1.$	+ 9.
+ 61 667	3054 C	F	G	16	-6.9 ± 1.4		
	3088 A	W	F	7	-4.1 ± 3.5		
	3089 A	F	F	21	-8.8 ± 2.1	$-7. \pm 1.$	- 6.
— 3 1685	3094 D	G	F	25	$+19.0 \pm 1.8$		
	3097 A	F	G	27	$+17.6 \pm 2.0$	$+18. \pm 1.$	+ 1.
+ 57 702	3044 A	W	G	16	-13.6 ± 2.6		
	3079 A	G	F	29	-10.6 ± 1.5	$-11. \pm 1.$	- 10.
+ 14 2048	3126 A	F	G	21	$+3.5 \pm 1.3$		
	3127 A	G	G	16	$+5.9 \pm 2.1$		
	3134 A	G	G	19	$+2.6 \pm 1.8$	$+4. \pm 1.$	- 5.
Average velocities considered positive						$23. \pm 1.$	14.9

and represents a compromise between the results obtained by proper motion and radial velocity determination. (*Astr. Jour.* 28, 167, 1914.) This direction was used by Campbell in his solution for solar motion by spectral types (*Lick Observatory Bulletin*, No. 196, 127, 1911.)

At the foot of the columns are given the averages of the radial velocities of Class R stars, 23 km. per second, and of the residual radial velocities, 15 km. per second. In this connection it is interesting to compare the average radial velocity

of 8 stars of Class N determined by Hale, Ellerman, and Parkhurst and exhibited in Table VI. The average radial velocity of 8 Class N stars is 11 km. per second. The residual radial velocities were not given in their paper, but were determined by the method given above for the sake of comparison with the results for Class R stars. The average *residual radial velocity* of 8 stars with spectra of Class N is 13 km. per second. On account of the small number of stars of Classes R and N for which the radial velocities have been

determined, their averages may only approximately represent the classes.

Average residual radial velocity of 10 Class R stars, 15 km. per sec.

Average residual radial velocity of 8 Class N stars, 13 km. per sec.

TABLE VI. RADIAL VELOCITIES, CLASS N.

STAR.	RADIAL VELOCITY.	RESIDUAL RADIAL VELOCITY.
74 Schj.	+ 5 km.	- 9 km.
78 Schj.	- 1	- 8
115 Schj.	- 13	- 22
132 Schj.	- 28	- 38
318 Birm.	- 10	- 3
152 Schj.	+ 1	+ 10
19 Piscium	- 2	0
280 Schj.	- 25	- 16
Average (positive)	11	13.2

For the sake of comparison with other types the following table is inserted. Part of the data is taken from *Lick Observatory Bulletin*, No. 196, 126, 1911. The values for Classes R and N were added by the writer.

TABLE VII. RESIDUAL RADIAL VELOCITIES ACCORDING TO SPECTRAL TYPE.

SPECTRAL TYPES.	NO. OF STARS.	AVERAGE RESIDUAL RADIAL VELOCITY.
O and B	141	8.99
A	133	9.94
F	159	13.90
G and K	529	15.15
M	72	16.55
R	10	14.9
N	8	13.2

QUALITATIVE RESULTS

General Characteristics. The general features of the spectrum of Class R stars have been given in the section on spectrograms; here we shall discuss the details at greater length.

The most conspicuous feature of the region of the spectrum under consideration (violet end to λ 5000), as previously pointed out, is the broad

absorption band with head at λ 4737, usually attributed to some form of carbon compound. The progression of intensity of this band in the spectrum of the different stars, suggesting an evolutionary series, has been used to establish the sequence, + 42° 2811, - 10° 5057, + 5° 5223 + 20° 5071, + 34° 1929, - 10° 513, + 61° 667, - 3° 1685, + 57° 702, + 14° 2048.

In general the spectrum having the strongest carbon absorption band shows the least light action in the violet. It is interesting at this point to inquire if other changes can be found accompanying the change in this underlying characteristic.

Naturally we expect the color index to indicate this transition. Data are lacking excepting for two stars of the list.

STAR.	COLOR INDEX.
- 10° 5057	1.09
+ 20° 5071	1.82

These two follow the proposed order. The visual colors of the 10 stars as recorded in our observational notes appear to be consistent with the sequence. The first one closely resembles the solar type.

Carbon. Accompanying the increase of intensity of the λ 4700 band, a peculiar transformation takes place in the bright region of the spectrum adjoining the head of the band. The absorption line at λ 4743.6 grows much stronger until at the middle of the series it resembles a new head of the band at λ 4745.1. Another line then appears at λ 4751.1, which follows a similar course and at the end of the series appears like a head of the band at λ 4752.8. No explanation is here offered.

In addition to λ 4737 other members of Group IV of the Swan spectrum, $\lambda\lambda$ 4715, 4697, 4684, are found in the spectra of some of the stars; in other cases, especially late in the sequence, they are not distinguishable on account of the strong absorption in this region. Group V, $\lambda\lambda$ 4381, 4371, 4365, is weak, if present; lines corresponding only to the second were measured on any of the plates, and they may be identifiable as a chromium line that is widened in sun spots.

Cyanogen Group II, $\lambda\lambda$ 4606, 4578, 4553, 4532, 4515, 4502, is represented in all of the stars by some of its lines. The intensity of the first of the group varies greatly, but not progressively; λ 4553 appears to grow stronger in the order of the sequence. The first of Cyanogen Group III, 4216, 4197, 4181, is strong; the second is present. In the case of the later stars, the spectrum is weak in this region and consequently the intensity of the lines cannot be compared from star to star. The "chief carbon line q"¹⁷ λ 4268 does not change appreciably in intensity with the sequence, but was not measured in all of the stars.

Chromium. A large number of strong chromium lines appear in the spectra of Class R stars. Many of them are identical with the strong lines of Classes I and II of the electric furnace emission lines investigated by King.¹⁸ We note especially $\lambda\lambda$ 4254.5, 4275.0, 4289.9, 4337.7, (4339.6-40.3?), 4352.0, 4407.0, 4530.9, 4580.3. No systematic change in intensity can be detected. Some of the strong furnace and arc emission lines, however, are not represented by absorption lines in the stellar spectra.

Vanadium. This element is also represented by numerous lines, the greater number of which are of King's classes I and II. The table of wave-lengths indicates the lines ascribed to Vanadium. No progressive change is noticeable.

Iron. Numerous iron lines are present, chiefly of King's Classes II and III.¹⁹ The most prominent are $\lambda\lambda$ 4187.9, 4250.6 (blend), 4260.6, 4271.9, 4325.9, 4404.9, 4415.3, 4494.7, 4871.9 (blend), 4920.7. No systematic change is noticeable.

Titanium. The presence of this element is well attested. Several of the lines show a weakening or broadening in the spectra of the later stars. Lines of Classes I, II, and III are most numerous.

Calcium. The line at λ 4227 is strong and broadens, passing along the sequence. The H and

K lines appear only on plates of the first star of the sequence.

Nickel. This element is probably present giving λ 4470.7 in some of the stars. It may contribute to λ 4714.6, which does not give accordant values of the wave-length in the series. λ 4866 is very uncertain.

Magnesium. λ 4352.1 may blend with chromium, λ 4351.9, to produce the strong line at λ 4352, which decreases in intensity along the series. λ 4481 is strong, apparently widening in the latter part of the series.

Hydrogen. Hydrogen lines appear on many of the plates, but they are not strong. $H\gamma$ grows poorer in the later stars, where it can scarcely be separated from a strong line at λ 4337.8 attributed to chromium. $H\beta$ appears as a good line with intensity 5 in the spectrum of the first star of the series. It was not measured in the second; it is weak in others, and widens in the later stars of the list.

The displacement of some lines or shift with spectral type determined by Albrecht²⁰ is indicated in the series of Class R stars. Fifteen of the lines traced through Albrecht's "Table of Wave-lengths Varying Progressively with Spectral Type" show a change in the same direction passing along the series of Class R stars to Class N. Since the change in wave-length with spectral type is small, seldom exceeding 0.2 Å from F to K, our test establishes only the direction of the variation, on account of the probable error of ± 0.12 Å in wave-length determination for a single line on a plate.

Plate VIII shows graphically the change in wave-length of λ 4435 with spectral class.

The progressive change in intensity of various lines as we pass along the series has been noted for the different elements. Comparison of these lines and their changes in intensity with a list of lines, whose intensity changes with spectral type²¹ from Miss Maury's Class VI to Class XVIII, indicates that, in general, the progressive change in intensity in our series corresponds with the direction given in the Harvard table.

Comparison with solar spectrum. The general resemblance of the spectra of Class R stars to

¹⁷ Crew and Baker; *Ap. J.* 16, 67, 1902.

¹⁸ Lines of Class I are relatively strong at a low temperature (1900°C) and strengthen slowly at higher temperature. Class II lines appear at the low temperature and strengthen rapidly with increase of temperature. *Ap. J.* 41, 1915.

¹⁹ Class III lines are absent or faint at low temperature (1900°C), appear at medium (2200°C) and strengthen rapidly at higher temperature.

²⁰ Cordoba Boletin, No. 1, 1911.

²¹ Harvard Annals, Vol. 28, p. 60.

SPECTRA OF CLASS R STARS

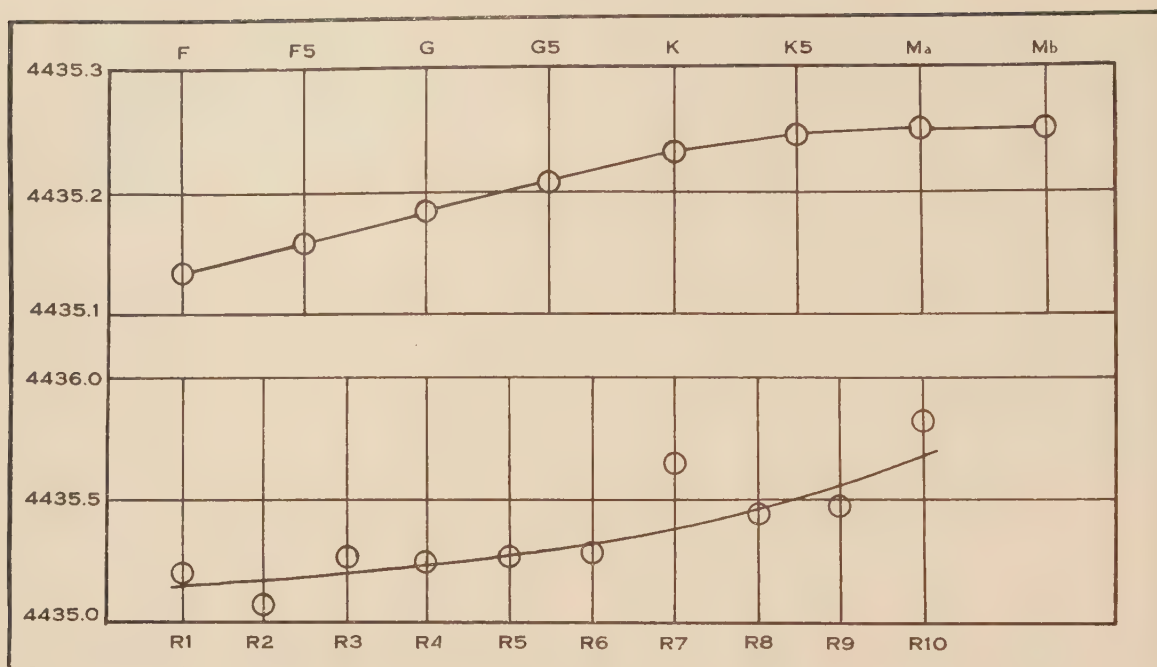


PLATE VIII. CHANGE IN WAVE-LENGTH OF $\lambda 4435$ WITH SPECTRAL CLASS
OBSERVATIONS OF UPPER CURVE BY ALBRECHT
OBSERVATIONS OF LOWER CURVE BY RUFUS

the solar spectrum with reference to metallic lines harmonizes with the similarity of Types II, III, and IV, pointed out by other writers. Referring to star — $10^\circ 5057$, Parkhurst says:²² "The spectrum resembles the solar type, with the addition of the dark $\lambda 4700$ band." He apparently considers that its spectrum differs greatly from the spectra of other stars of Classes N and R, which constituted his list for the determination of color indices, for he places it in a class by itself. We find, however, a very close resemblance between its spectrum and the spectrum of $+42^\circ 2811$, one of the recently discovered Class R stars which precedes it in our series. Its spectrum seems to fit well into the sequence adopted on page 136 above. We wish here simply to call attention to the close solar relationship of early Class R stars.

Hale, Ellerman, and Parkhurst have compared fourth type spectra with sun spot spectra and found that a large number of the lines widened in sun spots are strengthened in the spectra of fourth type stars. This result was based upon

²² *Ap. J.* 35, 131, 1912.

the region $\lambda 5190$ to the red end of the spectrum. From the work of Adams²³ we are able to make a similar comparison for Class R stars from $\lambda 5000$ to the violet end.

We have limited our count to the strongest lines of Adams' list, intensity at least 2, because with our slit width and dispersion, many of the faint lines do not appear. About two-thirds of the lines widened in the sun spots appear in Class R stars. Some others may be present, but concealed by the carbon and cyanogen absorption bands. We also note the omission of lines on the less refrangible side of the heads of these bands; e. g. opposite cyanogen $\lambda 4197$, the iron lines, $\lambda 4198.2$, slightly strengthened in spots; $\lambda 4198.4-5$, a strong blend slightly weakened; $\lambda 4198.8$, slightly strengthened and $\lambda 4199.3$, strengthened in spots, do not appear on our plates. Also below $\lambda 4447.3$ the strengthened lines $\lambda 4447.9$ Fe. and $\lambda 4449.3$ Ti. are not distinguishable. Among the lines weakened in sun spots, we find many weak or absent in Class R stars. Al-

²³ *Ap. J.* 27, 45, 1908.

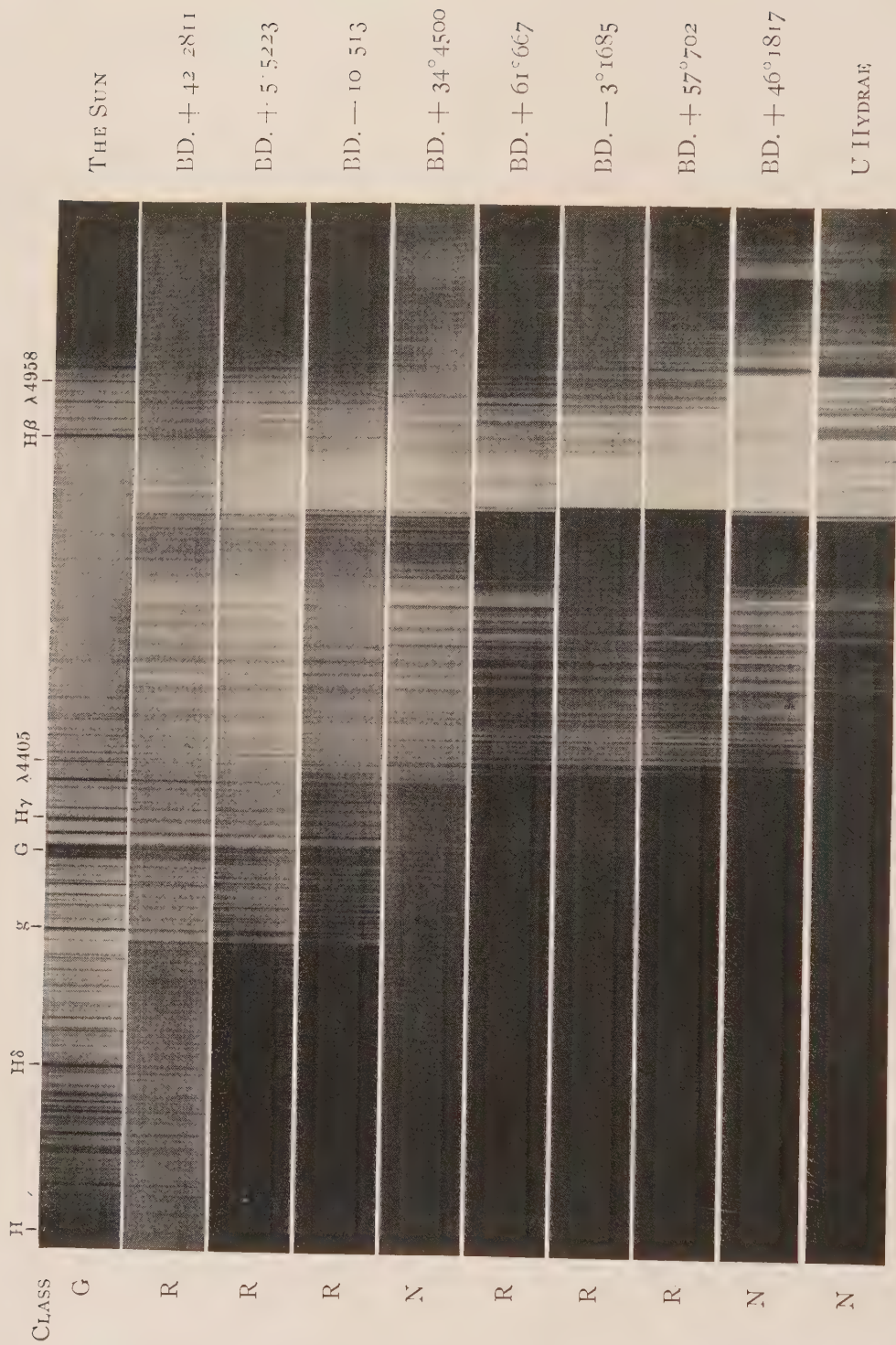


PLATE I. STELLAR SPECTRA ILLUSTRATING STEPS IN THE TRANSITION FROM
THE SUN TO STANDARD CLASS N

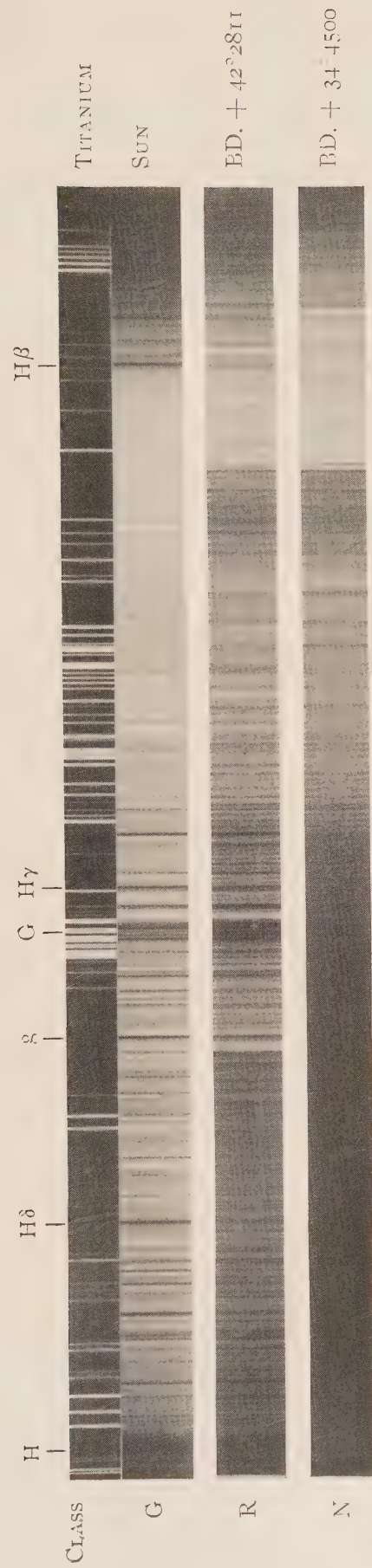


PLATE J. CLASS G, EARLY CLASS R, AND EARLY CLASS N SPECTRA, WITH TITANIUM SPARK COMPARISON

though there is some conflicting evidence the resemblance of the spectra of Class R stars and sun spot spectra seems to be well established.

Comparison with Class O. In the region of the spectrum under consideration, only the following coincidences occur in the bright lines of Classes O and R. The second column gives the number of Class R stars in which the bright line was measured.

CLASS R.	NO.	CLASS O.
λ 4464	4	4465-67 4473-74
4507	1	4504-10 4515-18
4538	.3	4534-44
4617	1	4592-98 4614-16 4650-54 4862

These coincidences are too few in number to establish any physical relationship. Both classes have bright lines, but this characteristic is shared with other classes.

In addition to the absence of some of the bright lines of Class O stars in the spectra of Class R, many bright lines found in the spectra of Class R stars are lacking in Class O.

There seems to be a shift in wave-length toward the red in the case of $\lambda\lambda$ 4589-91, 4818-20 and 4896-99, within the series of Class R stars.

The bright lines have not been identified. An explanation for the presence of some, at least, may be sought in the reversal of lines of known elements under certain conditions, rather than by the postulation of unknown elements.

Comparison with Class N. The chief difference between the spectra of stars of Class R and stars of Class N, from the violet end of the spectrum to λ 5000, is in the relative intensity of the spectrum on the two sides of the dark band with head at λ 4737. In general the spectra of stars of Class R extend farther into the violet than the spectra of Class N stars under similar conditions of exposure on stars of comparatively equal photographic magnitude. Ellerman's long

exposure on 19 Piscium²⁴ shows the presence of violet light in this Class N star, giving a spectrum beyond the Fraunhofer H and K lines; and Parkhurst expresses the opinion concerning the spectra of certain stars of Class N, "It is probably a mere question of exposure to extend the other spectra to this region, except perhaps that of 152 Schjellerup." The difference, then, appears to be due to a difference in the quantity rather than in the quality of the violet light emitted by stars of the two classes.

The presence of $H\beta$ as an absorption line in the spectra of many of the Class R stars, and its absence in Class N stars, or presence as a bright line, marks another difference. $H\beta$ has been observed, however, as a bright line in the Class R variables.²⁵

The cyanogen bands appear to be somewhat stronger in the spectra of Class N stars, especially λ 4553.6 and λ 4606. An unknown line λ 4443 (Ti spark λ 4444?) appears to be stronger in Class R than in Class N. On some of our plates it is very prominent, having a maximum line intensity of 10, while Hale does not mention it among prominent lines of Class N.

The progressive change in the wave-length of certain lines with spectral type passing from Class R to Class N has already been mentioned as taking place in the direction indicated by Albrecht.

The change in intensity of certain lines with spectral type has also been pointed out. These two features, however, could be better tested by the selection of some later Class N stars,²⁶ also by the observation of a larger number for wave-length determination.

Another noticeable difference is in the number and intensity of bright lines. The emission lines found in the spectra of Class R stars are in general very weak. In the case of the earlier stars, only a few faint ones were found, any one of which might be considered merely a slight increase in intensity of the continuous spectrum. Later in the series they become more numerous

²⁴ The Spectra of Stars of Secchi's Fourth Type, *Pub. of Yerkes Ob.*, Vol. II, page 260.

²⁵ *Harvard Circular*, 76.

²⁶ We have measured the plates of 19 Piscium, +76° 734, and +34° 4500, all of which are comparatively early Class N stars.

and are stronger, but are not so prominent on the plates of Class R stars as they are on Class N, especially on the plates of U Hydræ, the standard star of Class N.

Concerning the relative strength of carbon absorption in the two classes, we are able to compare the spectra of our series of Class R stars with the series of Class N stars of Hale, Ellerman, and Parkhurst.²⁷ Since the strength of the $\lambda 4700$ band was a determining factor in the arrangement of both sequences the series are practically duplicates. In both Classes R and N, we find stars in which the carbon absorption is relatively weak and others in which parallel degrees of intensity are evident down to the strong bands of $+57^{\circ}702$ (R) and 152 Schjellerup (N). Hale, Ellerman, and Parkhurst placed $+57^{\circ}702$ (R) at the end of their list of stars of type IV. It is evident, therefore, that the strength of carbon absorption is not a distinguishing feature between the two classes, but a factor which enters alike into the spectra of both types. We are thrown back, then, chiefly upon the criterion of general absorption in the violet to differentiate between the spectra of the two classes. This feature appears to be fundamental in the sequence B A F G K M. Although its application is difficult and fails to establish a definite line of demarkation between Classes R and N, the same difficulty is met in the case of other classes. In any natural system of classification, intermediate varieties frequently merge or overlap.

SUMMARY

Relation between Classes R and N. We shall now apply the accumulated data to the first part of our problem, viz., to establish a relationship between Classes N and R. Although the data are meager on some points and may be changed by later investigation, we shall use all in our possession. In Table VIII we tabulate a few results, using the solar type G as a basis of reference.

On all the points it appears that Class R precedes Class N, when the solar type is used as the point of reference.

The close resemblance of the spectra of Classes R and N, and the gradual transition from one to

the other with indications of overlapping in the case of the data of individual stars, prove that the two classes are closely related.

These facts indicate clearly that stars belonging to Classes R and N form a continuous sequence with R preceding N.

The place of Classes R and N in the Evolutionary Sequence. We shall now apply our results to the second part of our problem, viz., the relationship between Classes R and N and the sequence B A F G K M. In approaching this problem, two alternatives immediately present themselves: Do the Classes R and N follow M and form one continuous evolutionary sequence, or do they constitute a separate branch of the sequence coordinate with K and M? A more detailed study of the spectra of Classes K and M would be valuable in this connection, but is outside the scope of the present investigation.

Let us first consider some general questions relating to the assumption that spectral type is a linear function, with time as the independent variable. Evidently we are not at liberty to introduce another independent variable, so we must postulate an equal mass of primordial matter for each star, possessing exactly the same properties, and *surrounded by the same conditions*. Then we might expect all the stars to pass through the same evolutionary stages. However, the unequal distribution of stars in space, the presence of nebulous matter in some regions, and the unequal masses of determined systems, indicate that the conditions imposed are imaginary rather than real.

An application of the theory of evolution in other realms of science affords room for the genus to develop into species along diverging branches, possessing common genetic characteristics and different specific characteristics. This type of development may also obtain in stellar evolution.

Hale²⁸ has summarized the common characteristics of stars of Secchi's types III and IV.²⁹ 1. Red color. 2. Tendency to variability. 3. Resemblance of dark lines. 4. Presence of lines widened in sun spots. 5. Similar physical con-

²⁷ *Pub. of Yerkes Obs.*, Vol. II, Plate VIII of *The Spectra of Stars of Secchi's Fourth Type*.

²⁸ *Pub. of Yerkes Obs.*, Vol. II, 385.

²⁹ Type III approximately includes Classes K and M; type IV includes R and N.

ditions revealed by spectra. 6. Presence of bright lines. 7. Dark flutings; cyanogen flutings in common. 8. Connection of both types of spectra with spectra of solar stars. We may consider these to be the genetic characteristics.

The chief difference between the spectra of types III and IV is in the special absorption. Type III contains wide absorption bands sharp toward the violet and degraded toward the red, usually attributed to titanium oxide; type IV has similar bands, but reversed in appearance, being sharp toward the red, attributed to some form of carbon compound.³⁰ This constitutes the specific

Parkhurst has a spectrum resembling the solar type with the bands superposed. In this case the bands are stronger than in the preceding. The faintness of Class R stars and their scarcity lessen the probability of finding better intermediaries. Also, if the difference from the solar type were less, the probability of this difference being detected on a weak plate would be small.

The balanced condition of elements necessary to produce the Swan spectrum (distinguishing feature of Classes R and N) may lessen the probability that many stars exist with carbon bands. Baly³¹ calls attention to the fact that the presence

TABLE VIII. COMPARISON OF DATA.

	G.	R.	N.
Color Index	1.02	1.7	2.5
In galactic region	58 per cent.	63 per cent.	87 per cent.
Number of variables		8 per cent.	20 per cent.
Residual radial velocity	15.15 km.	14.9 km.	13.2 km. per sec.
Shift in wave-length with type		Slight.	Increased.
Change in intensity of lines		Noted.	Same sense.
Bright lines		Few and weak.	More numerous and stronger.
Hydrogen, H γ		Weak.	Weaker.
Hydrogen, H β		Present, and bright in variables.	Absent or bright.
Calcium, λ 4227	Present.	Widened.	Widened (Hale).
Cyanogen flutings	Absent.	Weak.	Stronger.

difference. We have, then, two types of spectra closely resembling each other, with respect to the line spectrum, with a different kind of absorption band superposed. These characteristics meet the conditions for coordinate branches of the evolutionary sequence.

The serious objection against this system of coordination raised by Pechule is that no examples of an intermediate type between the solar spectrum and type IV have been found. The spectra of the earliest stars of Class R seem to refute that objection. The carbon absorption of the first star of our series is comparatively weak, the spectrum extends as far as H and K, and the metallic lines give fair agreement with late solar type. The second star of the series according to

of a slight trace of oxygen in the source of light destroys the Swan spectrum due to carbon monoxide and produces the second band spectrum due to carbon dioxide.

However, in spite of these difficulties, as larger instruments are brought into use and the fainter red stars are more thoroughly studied, it is quite probable that examples will be found with weaker carbon bands than the first of the series photographed.

In addition to the qualitative similarity between types III and IV and the close correspondence between the earliest Class R stars and the solar type, we can make a comparison between the Classes R and K. These two classes should correspond quite closely, if the branching takes place following Class G. Perhaps R and K₅ are more

³⁰ Baly thinks the evidence is conclusive in favor of carbon monoxide. *Spectroscopy*, p. 444, 1905.

³¹ *Spectroscopy*, p. 444, 1905.

nearly parallel. We shall use data for K5 when available. A comparison follows showing a close correspondence.

	K OR K5	R.
Color index	1.64	1.7
Percentage in galactic region	56	63
Residual radial velocity, G and K	15.15	14.9 km. per sec.
Percentage of variables	Small	8

The correspondence is maintained also by the close similarity of the absorption lines, the shift in wave-length of certain lines with spectral type, the change in intensity of certain lines, absence or weakness of bright lines, weakness of cyanogen flutings, widening of $\lambda 4227$, and presence of hydrogen lines.

The close resemblance of the spectra of early Class R stars to the solar type, the parallelism between Classes R and K, together with the fulfillment of the conditions for coordinate branches by the two great classes of red stars (Secchi's types III and IV) lead to the conclusion of the second part of our problem, that the evolutionary sequence is divided, Classes K and M forming one branch and Classes R and N forming the other.

PHYSICAL CONDITIONS

The question arises: What physical conditions differentiate between stars of Classes N and R? Hale has interpreted the physical conditions of fourth type stars. Carbon vapor lies close to the photosphere above which are gases producing the bright lines of the spectra. The thick layer of dense atmosphere produces a strong general absorption. On the basis of this interpretation, the atmosphere of Class R stars is not so thick nor so dense as that of Class N stars and produces less general absorption, permitting the escape of a larger proportion of violet rays, which suffer most from general absorption.

Kapteyn³² has accumulated much evidence bearing upon the question of the change of spectrum due to the absorption of light in space. Parallax data are not available to determine whether this effect is evident as a differentiating factor between the stars of Classes R and N.

³² *Aph. J.* 40, 187, 1914.

Another question may arise: How can a solar type evolve two different types of stars? This question suggests another, the burden of proof of which rests with the advocate of the linear evolutionary sequence with R and N following M. How can a star, in which titanium oxide gives the characteristic feature of the spectrum, change into a star in which carbon monoxide predominates? An attempt to answer the first of these two questions seems more probable of success.

Given two stars of solar type under the same conditions, with equal masses, equal volumes, the same constituent elements, and surrounded by the same conditions in space, and the evolution of two different types would appear to be improbable. However, two stars of solar type drifting in different directions, as proper motion indicates, through time and space unlimited, may eventually encounter dissimilar conditions and differentiation may take place.

Moreover, it is quite probable that a differentiation begins before the solar type is reached. Nascent stars will be changed according to the properties of their own constituent elements and the characteristic elements of the matter pervading the surrounding region of space. Both of these factors may vary in different stars. If one region of space or a certain set of conditions is more favorable to the production of carbon and another to the existence of titanium, we may have in different stars of the solar type the right relationship between the various elements for the evolution of two different types of stars, one giving a spectrum in which the carbon bands predominate, the other producing a spectrum characterized by the bands of titanium oxide.

It is a curious fact that we find both elements, carbon and titanium, present in both classes of stars, type III with titanium bands and type IV with carbon bands. The type of spectrum apparently is due to the adjustment between the various elements. Possibly the predominance of carbon vapor in the form of carbon monoxide in the star's atmosphere suppresses the absorbing power of titanium oxide or *vice versa*. The discovery of a stellar spectrum showing the presence of both kinds of bands, carbon and titanium, would be both interesting and instructive. On

account of the delicate balance of elements that would perhaps be necessary to produce such a hybrid, its existence is quite improbable. The delicate adjustment between carbon and oxygen suitable for the production of the Swan spectrum, which has previously been mentioned, may account for the comparatively small number of stars belonging to Classes R and N.

CONCLUSIONS

The radial velocities of ten Class R stars have been determined, with an average probable error ± 1 km. These radial velocities range from -49 km. to $+25$ km. per second, and yield an average residual radial velocity of 14.9 km. per second.

Wave-lengths of heads of bands, absorption lines and emission lines of Class R stars have been determined, (probable error of the mean in ten plates ± 0.05 Å) for the region $\lambda 4185$ to $\lambda 5000$.

The following substances were identified: Carbon (carbon monoxide and cyanogen), hydrogen, chromium, vanadium, titanium, iron, sodium, calcium, magnesium, nickel, and manganese.

Spectrograms of five Class O stars were made for comparison with Class R. No close resemblance was found.

Spectrograms of five Class N stars were obtained, part of which were measured and reduced, for qualitative comparison with Class R stars.

The chief difference between the spectra of stars of Class R and stars of Class N is due to general absorption.

Sixty-three per cent. of Class R stars are in

the galactic region ($+30^\circ$ to -30° galactic latitude).

The average color index of five Class R stars (Parkhurst) is 1.7.

The number marked variable in the Harvard tables is 8 per cent.

There is a shift in wave-length and change in intensity of certain lines with spectral type through the R N sequence in the same order as G to M.

Bright lines are not so numerous nor so strong in Class R as in Class N.

Class R precedes Class N in the evolutionary sequence taken in the usual order B A F G K M.

There is a close resemblance between the solar spectrum and the spectra of the first stars of the Class R series.

A marked correspondence exists between Classes R and K in color index, distribution with reference to galaxy, residual radial velocity, tendency to variability, similarity of absorption lines, bright lines, cyanogen flutings, $\lambda 4227$, and hydrogen lines.

The evolutionary sequence divides at the solar type, Classes K and M forming one branch, and Classes R and N constituting the other.

Stars of Class R form the connecting links between Class N and the solar type.

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